Note that inflaton Φ has mass in the range of 10^{11} GeV, the SM Higgs with mass ~ 126 GeV, and other fields A_4, H_4, H_5 and φ^0 with masses in TeV scale.

3. CONCLUSION

In this paper we have studied the scalar sector of the 3-3-1 model containing axion as DM candidate. The diagonalization of 4×4 square mass matrix for the CP-odd sector is exactly fulfilled. Our results show that the axion is mainly contained from the CP-odd part of the singlet φ, while the CP-even component of the later is the inflaton of the model. The positivity of the masses leads to constraints for some couplings of the Higgs sector: only λ_3 is negative, while coupling constants λ_φ and $\lambda_i, i = 1,7,8,9,10$ are positive.

Note that the axion in the model under consideration is still massless. Our next task is to make it massive by introducing soft breaking mass term.

Acknowledgments

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BỘ THẾ HIGGS TRONG MÔ HÌNH 3-3-1 VẬT CHẤT TỐI AXION

Tóm tắt: *Bộ thế Higgs trong mô hình 3-3-1 với vật chất axion được mô tả. Ma trận khối lượng 4x4 cho phần lẻ CP được chéo hóa chính xác. Kết quả chỉ ra rằng axion xuất hiện ở phần lẻ CP trong khi phần chẵn CP chứa lạm phát. Tính dương của khối lượng dẫn tới chúng ta giới hạn được một số hằng số tương tác trong bộ thế Higgs.*

PACS: 11.30.Fs, 12.15.Ff, 12.60.-i

Từ khoá: *Bộ thế Higgs, axion, vật chất tối.*

INFLUENCE OF THE GRAPHENE SIZE ON THE ABSORPTION COEFFICIENT OF WEAK ELECTROMAGNETIC WAVE IN TWO-DIMENSIONAL GRAPHENE

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Abstract: *On the basis of the quantum kinetic equation has received analysing expressions for current density and absorption coefficient of electromagnetic wave in two-dimenssional graphene (2D graphene) with electron- optical phonon scattering is dominant. The dependence of the absorption coefficient into the parameters characteristic for the external wave field and the size parameters of graphene is very complex and nonlinear. The results are calculated, graphed proved well for theoretical results. The results are comparable to the case in the normal semiconductors indicating the difference, and results are new.*

Keywords: *Absorption coefficient, Quantum kinetic equation, 2D Graphene.*

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I. INTRODUCTION

Two-dimensional (2D) graphene was first studied by the scientists Andrei Geim and Konstantin Sergeevich Novoselov on the transport of electrons and holes. They were awarded the 2010 Nobel Prize in Physics [1]. Graphene is a flat sheet about the thickness of an atomic layer of carbon atoms, which forms a honeycomb shaped array. The length of carbon-carbon bond (C-C) in graphene is about 0.142 nm. 2D graphene is important in making graphene transistors in electronic chips and can replace existing silicon transistors.

Graphene has the ability to fill its electron holes with other electrons almost instantly, meaning it transfers a large amount of charge in an extremely short amount of time. Graphene is a separate carbon atom sheet bundled into a two-dimensional (2D) honeycomb network, which is the basis of graphite-like materials of different dimensions. It can be encapsulated into non-dimensional fluleren (0D); rolled into one-dimensional nanocarbon tubes (1D); or folded into 3D graphite (three dimensions) [2]. Put simply, graphene is a sheet of graphite separated at atomic size.

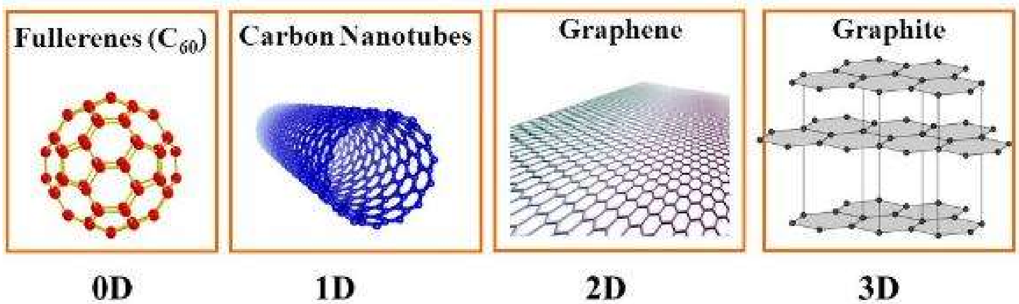


Fig.1: *Low-dimensional graphene: zero-Dimensional (0D), one-dimensional (1D), bidirectional (2D) and three-dimensional (3D)*

Twenty years ago, the term "nanotechnology" was little known, but now it has become a familiar term at every stage of modern society. Nanometer is the abbreviation for nanometer (symbol nm, 1 nm = 10^{-9}m) is a unit of measurement in the atomic system. Nanotechnology involves taking advantage of new physical phenomena (quantum-stimulating effects) in nanometer-sized materials to create materials with special functions.

Although the theory does not accept an all-crystal lattice in 2-dimensional space, that is, on an absolute plane, but it does not prohibit a 2-dimensional lattice that relies on a 3-dimensional cube. This is true for the observations of Geim, Novoselov et al. in [3]. Under the microscope they were able to observe suspended graphene plaques in a state of non-flat free space, which were as protruding as the microscopic wavefront in three-dimensional space (Fig. 2).

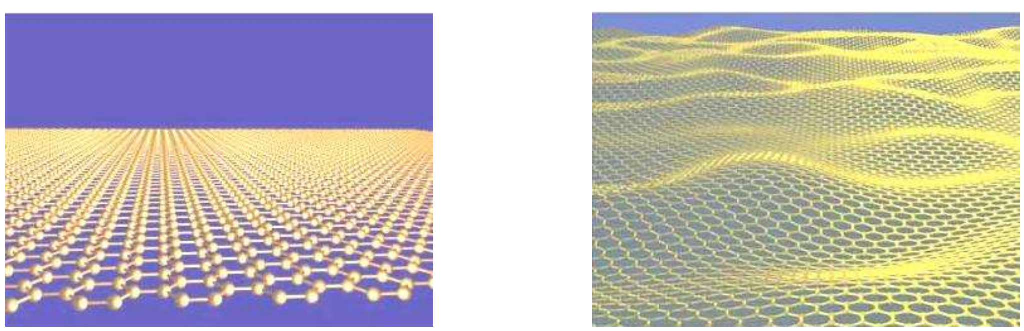

(a) (b)

Fig. 2: *Graphene does not exist in an absolute plane (a),but existing with the convex surface of the 3D space (b).*

Graphene is considered to be a super-thin, electrically conductive, heat-resistant material that is 100 times stronger than steel. With such superior structure, the study of properties of graphene systems attracts the attention of scientists. Many physical phenomena are of interest and research in low dimensional physics due to the quantum size effect of materials. The effect of electromagnetic absorption is one of those research directions. This effect has been studied relatively sufficiently in normal semiconductor (3D) materials as well as other low-dimensional semiconductors (0D, 1D, 2D) both theoretically and empirically (for example, in [4]). In the movement of free particles in low-dimensional materials, the interaction between the carrier and the phonon is the most significant contribution. This means that when the electron moves in the crystal lattice of the materials, it will be affected by electromagnetic waves in the direction of acceleration, and also affected by the oscillation of the crystal lattice in the direction of motion impedance. With the assumption that the strongly variable electric field is a flat electromagnetic wave and that the propagation of this electromagnetic wave along the Oz axis of the material has a decreasing electromagnetic wave intensity. The characteristic quantity for reducing the intensity of the electromagnetic wave when going deep into the semiconductor is called the electromagnetic absorption coefficient. Investigating the strong electromagnetic absorption coefficient caused by the electron-phonon interaction is a classic but very important problem because this is the effect that occurs in semiconductor materials present in electronic accessories. The theory of electromagnetic nonlinear absorption in cubic semiconductors has been studied and published by V. Pavlovich and E. M. Epshtein since 1977 [5] on the basis of the method of quantum dynamic equations for electronics. With graphene materials, in the world in recent years, there are also a number of groups of authors studying the magnetic - phonon resonance effect [6] with the interaction process between electron - phonon in graphene. Good results and consistent with experiment. However, the coefficient of electromagnetic wave absorption in Graphene 2D has not been studied. Therefore, we are interested in studying this physics problem. In [7], we formulated quantum theory for the absorption of weak electromagnetic wave in 2D graphene and received analytical expression for the absorption coefficient. Numerical calculations show the nonlinear dependence of the absorption coefficient on the frequency of electromagnetic wave, wave intensity and temperature of the system. In this paper, we continue to study the effect of graphene size on absorption coefficient. Results are calculated, graphed and discussed.

2. CONTENT

2.1. The 2d graphene lattice structure

Graphene is a lattice layer of two-dimensional carbon atoms separated from graphite. Graphene has a hexagonal structure like a honeycomb (Fig. 3). This special nano structure has excellent properties such as good electrical conductivity due to high carrier mobility, very mechanical and thermal stability. Therefore, each carbon atom is linked to the three nearest carbon atoms by the bonds created by the overlap of s-p orbitals, corresponding to the sp2 hybridization state.

The $2p_z$ trajectory perpendicular to the graphene sheet will not participate in the hybridization process but will overlap and form liên bonds, which are not localized, will form conductive regions π and create irregular electrical properties. graphene (Fig. 4 and Fig. 5). Although graphene has a high symmetry in the structure, the hexagonal cell in graphene was not chosen as the unit cell because the adjacent carbon atoms are not equivalent. However, we can consider graphene lattice as a combination of sub-lattices including carbon atoms at A and carbon at B, so the surrounding carbon atoms are completely equivalent each in terms of structure and properties. The graphene lattice structure can be described by the unit vectors of these subnets. The elemental vectors $\vec{a}_1, \vec{a}_2$ are valued as [8]:

$\vec{a}_1 = \frac{a}{2}(3, \sqrt{3})$; $\vec{a}_2 = \frac{a}{2}(3, \sqrt{3})$; $a_{\min} = 0{,}142\, nm$, with a is the lattice constant.

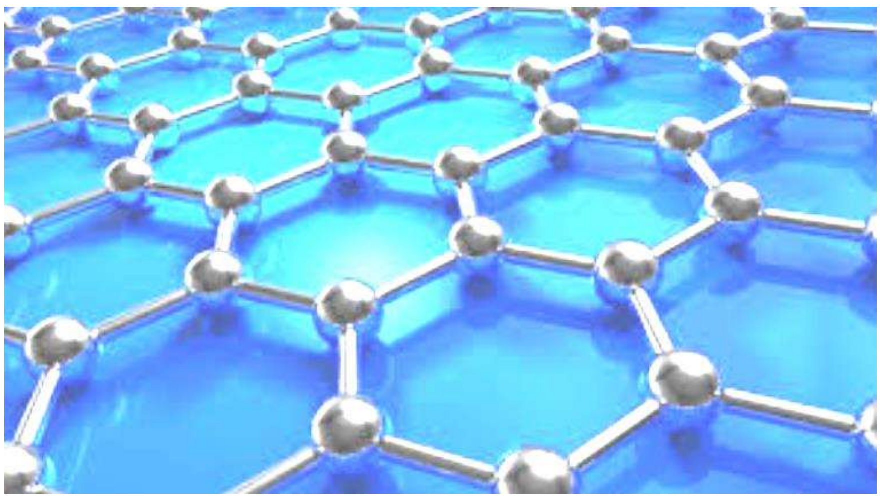
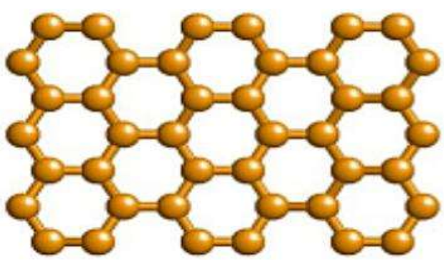


Fig. 3: *Graphene crystal structure (hexagonal structure, also known as honeycomb structure)*



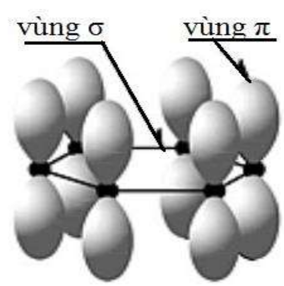


Fig. 4: *Bonds of C atoms in graphene lattice and illustrate the regions σ and the region π*

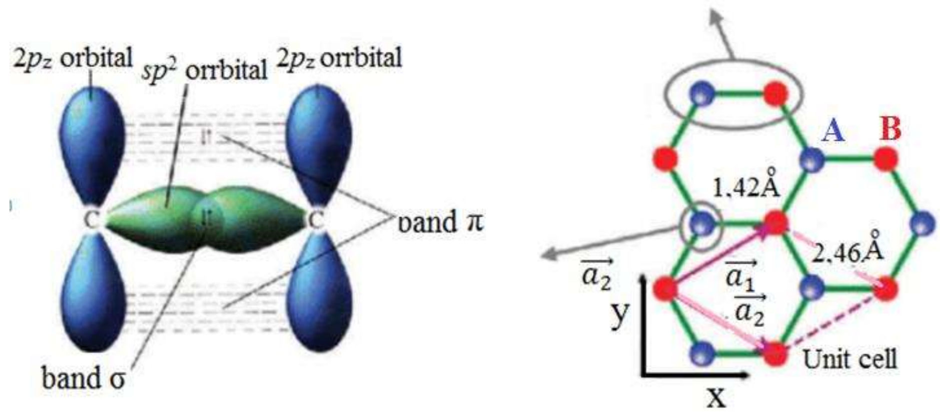


Fig. 5: *2D graphene lattice structure*

2.2. The carrier current density and absorption coefficient of a weak electromagnetic wave in 2d graphene

A high-frequency electromagnetic wave is applied to the system in the z direction with electric field vector $\vec{E} = \vec{E}_0 \sin\Omega t$ with $\vec{E}_0$ and Ω are the amplitude and the frequency of the electromagnetic wave, respectively. Assume 2D graphene lattice is in the oxy plane in the magnetic field $\vec{B} = (0,0,B)$, then the wave function and energy spectrum the electron in graphene [7] have the following form (1) and (2):

$$\vec{F}_{n,X}(\vec{r}) = \frac{C_n}{\sqrt{L}} \exp\left(-i\frac{Xy}{l^2}\right) \begin{bmatrix} sng(n) h_{|n|-1}(x-X) \\ h_{|n|-1}(x-X) \end{bmatrix} \quad (1)$$

$$\varepsilon_n = S_n \hbar\omega_B |n|^{1/2} , \quad (2)$$

where:

$$C_n = \begin{cases} 1 & n=0 \\ \frac{1}{\sqrt{2}} & n \neq 0 \end{cases} ; \; sng(n) \equiv S_n = \begin{cases} 1 & n>0 \\ 0 & n=0 \\ -1 & n<0 \end{cases} ; \; h_{|n|-1}(x) = \frac{i^{|n|}}{\sqrt{2^{|n|}|n|!\sqrt{\pi}l}} \exp\left[-\frac{1}{2}\left(\frac{x}{l}\right)^2\right] H_{|n|}\left(\frac{x}{l}\right) ;$$

L - the linear dimension of the system; X - a center coordinate, $H_n(t)$ – the Hermite polynomial; $l = (c\hbar/eB)^{1/2}$, $n = 0, \pm 1 \ldots$; $\hbar\omega_B = \sqrt{2}\gamma/l$ is the effective magnetic energy.

Procced from the hamiltonian of the electron - optical phonon systein 2D Graphene in the second quantization presentation can be written as [9] :

$$H = \sum_{n,\vec{k}_\perp} \varepsilon_n \left[\vec{k}_\perp - \frac{e}{\hbar c}\vec{A}(t)\right] a^+_{n,\vec{k}_\perp} a_{n,\vec{k}_\perp} + \sum_{\vec{q}} \hbar\omega_{\vec{q}} \left(b^+_{\vec{q}} b_{\vec{q}} + \frac{1}{2}\right) + \sum_{n,n',\vec{q},\vec{k}_\perp} M_{n,n'}(\vec{q})\, a^+_{n',\vec{k}_\perp+\vec{q}} a_{n,\vec{k}_\perp} \left(b^+_{-\vec{q}} + b_{\vec{q}}\right) \quad (3)$$

where: $\vec{A}(t)$- the vector potential of an external electromagnetic wave; *n* denotes the quantization of the energy spectrum in the z direction (n = 1, 2, 3, ...); $\vec{k}, \vec{q}$ respectively are wave vectors of electron, phonon, $(n, \vec{k}_\perp)$, $(n', \vec{k}_\perp + \vec{q}_\perp)$are electron states before and after scattering, respectively, $\vec{k}_\perp$ is in plane (x,y) wave vector of the electron. $a^+_{n,\vec{k}_\perp}$, $a_{n,\vec{k}_\perp}$, $b^+_{\vec{q}}$, $b_{\vec{q}}$ are the creation and annihilation operators of electron,phonon, respectively, $\vec{q} = (\vec{q}_\perp, q_z)$; $M_{n,n'}(\vec{q})$ is the matrix factor of electron in the formula

$$\left|M_{n,n'}(\vec{q})\right|^2 = \hbar D_{op}^2 (2\rho L^2 \omega_{\vec{q}})^{-1} C_n^2 C_{n'}^2 \frac{m!}{(m+j)!} e^{-u} u^j \left[L_m^j(u) + S_n S_{n'} \sqrt{\frac{m+j}{m}} L_{m-1}^j(u)\right], \quad (4)$$

with: ρ is mass density of 2D Graphene, D_{op} is deformed potential of optical phonon; $L_j^m(u)$ is the associated Laguerre polynomial, $u = \ell^2 q^2/2$, $q^2 = q_x^2 + q_y^2$, $m = \min(|n|, |n'|)$, $j = \big||n| - |n'|\big|$.We calculated and received quantum dynamic equation for electronics in the 2D graphene (5) and the nonlinear absorption coefficient (6) in 2D graphene [7], written as follows:

- *The carrier current density expression in 2D graphene*:

$$\vec{J}_\perp(t) = -\frac{e}{m^* c} \sum_{n,\vec{k}_\perp} \vec{A}(t) n_{n,\vec{k}_\perp}(t) + \sum_{\ell=1}^{\infty} \sin(\ell\Omega t) \frac{2\pi e\hbar^2}{m^* l\Omega} \sum_{n,n'.\vec{k}_\perp,\vec{q}} \left|M_{n,n'}(\vec{q})\right|^2 \sum_{k=-\infty}^{\infty} \vec{q}_\perp J_k\left(\frac{e\vec{q}_\perp \vec{E}_o}{m^*\Omega^2}\right)$$
$$\times \left[J_{k+l}\left(\frac{e\vec{q}_\perp \vec{E}_o}{m^*\Omega^2}\right) + J_{k-l}\left(\frac{e\vec{q}_\perp \vec{E}_o}{m^*\Omega^2}\right)\right] N_{\vec{q}} \left(\overline{n_{n,\vec{k}_\perp}} - \overline{n_{n',\vec{k}_\perp+\vec{q}}}\right) \delta\left(\varepsilon_{n',\vec{k}_\perp+\vec{q}} - \varepsilon_{n,\vec{k}_\perp} + \hbar\omega_o - k\hbar\Omega\right) \quad (5)$$

where: $\overline{n_{n,\vec{k}_\perp}} \equiv f_{n,\vec{k}_\perp}$ is the time - independent component of the electron distribution function; $\overrightarrow{N}_q$ is the time-independent component of the phonon distribution function; $\delta(x)$

is the Dirac delta function; $J_k(x)$ is the Bessel function [9] and the quantity δ is infinitesimal and appears due to the assumption of an adiabatic interaction of the electromagnetic wave. Note that, the motion of electrons is confined along the z direction in a 2D Graphene, so we only consider the in plane (x, y) current density vector of electrons $\vec{J}_{\perp}(t)$.

- *The nonlinear absorption coefficient of the electromagnetic wave in 2D graphene:*

$$\alpha = \alpha_0 \frac{L_x L_y}{l^6 \Omega^3} \left[\exp\left(\frac{\hbar\omega_0}{k_B T} - 1 \right) \right]^{-1} \sum_{n,n',N} f_{n,N} C_n^2 C_{n'}^2$$
$$\times \left[(2m+j+1) - 2S_n S_{n'} \sqrt{m(m+j)} + S_n^2 S_{n'}^2 (2m+j-1) \right] \Gamma_o (\varepsilon^2 + \Gamma_o^2)^{-1} \quad (6)$$

with:

$$\alpha_0 = 2\pi\hbar e^2 D_{op}^2 S_o c^{-1} L^{-2} (\chi_\infty \rho \omega_0 m^{*2})^{-1/2} \quad ; \quad (7)$$

$$\Gamma_o = \gamma\, \hbar\omega_B D_{op} (8\hbar\pi\rho\omega_o)^{-1/2} \; ; \quad (8)$$

$$f_{n,N} = \frac{n_o^2}{\pi^2} \left[\hbar\Omega_B (\mathrm{N} + \tfrac{1}{2}) + \frac{\pi^2 n^2 \hbar^2}{2m^* L^2} \right]^{-2} \left(1 - \exp\left[- \frac{m^* \Omega}{\hbar\Omega_B (\mathrm{N} + \tfrac{1}{2}) + \frac{\pi^2 n^2 \hbar^2}{2m^* L^2}} \right] \right)^2 \; ; \quad (9)$$

$$\varepsilon = \varepsilon_n - \varepsilon_{n'} + \hbar\omega_0 - \hbar\Omega \; , \quad (10)$$

where: n_0 is the equilibrium distribution function of the electron [10]; S_o is unit acreage of 2D graphene lattice χ_∞ is the high-frequency dielectric constants; $N = 0, \pm 1, \ldots$; $m = \min(n, n')$; $j = \big||n| - |n'|\big|$; γ is the conductivity coefficient.

2.3. Numerical results and discussion

In [7], the nonlinear absorption coefficient α is calculated and plotted when considered as a function depending on the parameters: temperature T, frequency of electromagnetic wave $\mathbf{\Omega}$, magnetic field intensity B. Below, we continue to calculate the number and plot the dependence of the nonlinear absorption coefficient on the size of the 2D graphene sheet. The parameters used in computational calculations are as follows:

$$\rho = 7,7.10^{-8} g.cm^{-2};\; D_{op} = 1,4.10^{-9} eV.cm^{-1};\; k_B = 1,3807.10^{-23} J.K^{-1};$$
$$\hbar\omega_o = 6$$
$$\hbar = 1,05459.10^{-34} J.s;\; \chi_\infty = 10,9;\; \gamma = 6,46\, eV.\overset{0}{A}.$$

The graph in Fig.6 shows clearly the dependence of the nonlinear absorption coefficient on the size of the Graphene sheet. When the graphene sheet has a longer length, the absorption of electric waves in the graphene will be stronger. This dependency is the basis for implementing standards for two-dimensional graphene fabrication technology. That gives us more complete technology of making Graphene sheet to apply it in high-end, super small, versatile and intelligent electronic components.

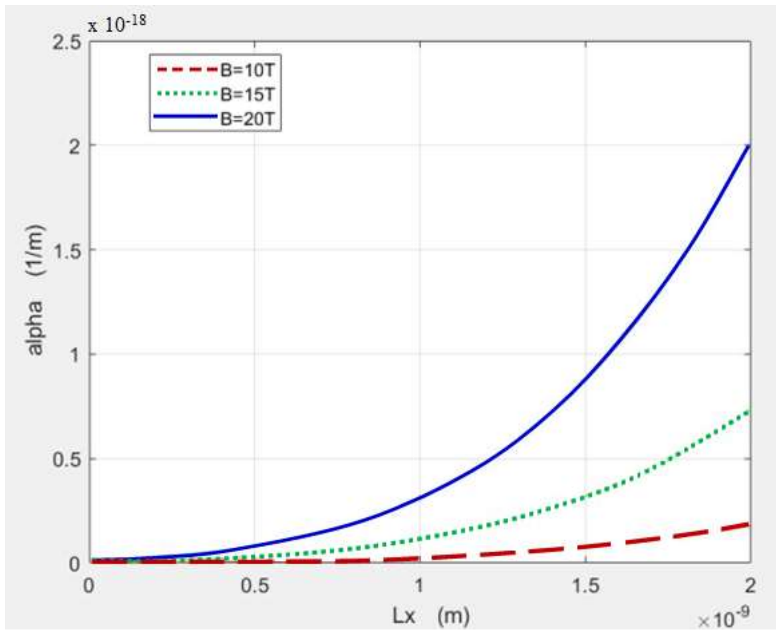


Fig. 6. *The dependence of coefficient α (alpha) on graphene lattice thickness*

The results obtained above are the basis for new research directions in theory and experiment in 2D graphene. The physical problem could expand for electron- acoustic phonon scattering, or the presence of electromagnetic waves have a strong variable amplitude.

3. CONCLUSION

In this paper, on the basic of quantum kinetic equation, We obtained the analytic expressions of current density and nonlinear absorption coefficient of a electromagnetic wave in 2D graphene for the presence of an external magnetic field. The electromagnetic wave is assumed high-frequency with weak amplitude. Results are numerically calculated, graphed to clarify the dependence of absorption coefficient on the size of 2D graphene. In [7], we have shown the magnetic resonance region. At each of the different values of the magnetic field, the absorption coefficient reaches the maximum value with different amplitudes of oscillation.

Note that, because amplitude of electromagnetic wave is weak should have influence of electromagnetic wave intensity on the absorption coefficient is negligible. So, in this paper we used the quadratic approximation of the Bessel function to simplify the physic problem.

Graphene interacts with electric waves from the infrared to the ultraviolet region. We know that silicon and other semiconductors also interact with electromagnetic waves but only in the infrared region. Graphene induce with electromagnetic waves stretches from the microwave zone (cm wavelength) to the ultraviolet region (nm wavelength). Therefore, the intensity of graphene's interaction with electromagnetic waves is superior to the conducting polymers and nanotubes. To date, no theory has ever been able to explain why photons can affect organic materials that conduct electricity in a wide range of waves from centimeter to nanometer [11]. Therefore, physicists and electronics engineers are still actively researching and searching for useful applications of graphene in optoelectronics [12].

In particular, the intensity of the interaction of graphene is very strong with terahertz waves (Terahertz waves are located between microwaves and infrared waves). Terahertz waves can see through fabric, plastic but are absorbed by metals and inorganic compounds, so this is the wave used to detect weapons, explosives hidden in people or in luggage. The interaction of graphene in region of terahertz wave shows the potential of using graphene in future anti-terrorist terahertz sensors.

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