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Plasma Waves in Type I and II Two-Dimensional Impure Superlattice due to Excitation of Electromagnetic Waves

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Abstract- In this paper, the changes of conductivity tensor in type I and II impure superlattice with localized levels due to excitation of electromagnetic waves with using two dimensions electron absolute gas and irregularity approximation is calculated. Seen that the real part of conductivity tensor has a peak of 0.24% which is not seen in the pure samples and it is shown that, this change is caused by electrons localization**.**

Keywords- *superlattice, electromagnetic waves, two dimensions electron*

I. INTRODUCTION

Two-dimensional electron gas systems (2DEG) have been widely studied in few recent decades. Here in these systems, say, the superlattices, the free components are dislocated in a two-dimensional space although they already have moving limitations in the third dimension. The superlattice is one of the two-dimensional systems having a periodic artificial structure including alternative layers with a nanometer size of thickness from two-dissimilar semiconductors [1, 2].

II. PLASMON WAVES IN IMPURE SUPERLATTICES

In a single-layer two-dimensional electronic gas system, an intensive stimulation of Plasmon is produced by a network diffraction grating in a sample mode. in this net, the two-dimensional Plasmon momentum K and the absorbing intensification is $\omega = \omega_p(k)$ in which ω is the frequency of the inter electromagnetic wave and ω_p is the two-dimensional plasma frequency. So we are currently having a superlattice of semi-infinite multi layers under our study having been occupied in a zone with the condition z>0 and a produced similar alternating structure.

The electric field of passing wave from the network diffraction grating has been shown through a Fourier series of $\cos K_s(x)$ in which $K_s = \frac{2\pi s}{L}$ where L is the period of the net and s=0,1,2,… , doesn`t stimulate the harmonic zero of the plasma fluctuations. These harmonics don`t produce waves in z direction and the electric field decreases exponentially with the increase of the net surface. The wavelength infrared radiation is extremely longer than the Plasmon frequency wavelength under these regular vitro.($\omega \sim 10^{12}$-10^{13})thus, the harmonic electromagnetic wave passing through the net should be proportionate to exp ($i K_s x - K_s z$).Therefore, in order to put the stimulation of semi-infinite superlattice under study, it`s justified if the thickness is much bigger than $\frac{1}{K}$.

So the harmonics with s>0 become the plasma oscillation as a result of the intensive interaction with plasma superlattice. Travelling waves which carry energy inside the superlattice gives group velocity dispersion by the law of the plasmons in layered structures. The first harmonic intensity can reach to 10% of radiation intensity [3].

In this paper we`ll acquire the dispersion equation for two-dimensional electron gas in a superlattice plasmon wave in the presence of impurities and obtain the localized states [1]. Dispersion equation can be obtained through electron gas conductivity tensor .This value is calculated by taking the localized states. In Z=0, we consider the two-dimensional electron gas at the surface is absolute. This system for a superlattice is for example between InGaSb and an environment including the permittivity) InAs) ε_0 . Near the two-dimensional conductivity, electron dispersion law can be considered isotropic, uniform and square.

$$\varepsilon = \frac{p^2}{2m} \qquad (1)$$

In which m is the effective mass of electrons and $\vec{p}$ is their momentum. Mainly for low temperatures and electron scattering, lattice defects and impurities of atoms haven`t been investigated.We have also considered that the low electronic absorption range which has been irrigularly scattered.

The average distance between them $n_i^{-\frac{1}{2}}$ (in which, n_i is the density of impure atoms) is the greatest parameter with dimension of length,The scattering of electrons in atom can be obtained by calculating the conductivity tensor considering the collision frequency ν , which has been assumed constant or in the best case a floating (fluent) energy function [4].So by solving the wave equation and the boundary condition we will have:

$$j_i(\vec{q},\omega) = \sum_{k=1}^{2} \sigma_{ik}(q,\omega) E_k(q,\omega) \quad (2)$$

In which $\vec{E}(q,\omega)$ and $\vec{j}(q,\omega)$ are the two-dimensional Fourier components of the vectors $\vec{E}$ and $\vec{j}$ which Ohm`s law connects these two together and also σ_{ik} is the two-dimensional conductivity tensor. As a result, we can now obtain the plasmon dispersion equation [5]:

$$\left[\sigma_{xx} + i\frac{\beta c^2}{2\pi\omega}\right]\left[\sigma_{yy} - i\omega\frac{\varepsilon_0}{2\pi\beta}\right] - \sigma_{xy}\sigma_{yx} = 0 \quad (3)$$

Two-dimensional electron gas with regard to the system of absolute boundary between the two-half space permittivity coefficients ε_1 and ε_2, electrons moving in the Z =0 will be offset by the positively charged ions(impurity absorption).

When the average distance between the electrons is $n_e^{-\frac{1}{2}}$, which is substantially larger than the Bohr radios, we can calculate the two-dimensional plasmon damping range by getting use of Boltzmann`s statistics. Electron-electron interactions have been considered by help of irregularities phase approximation. So, the interactive Coulomb energy at z=0 is equal to:

$$v' = \left[\frac{k\hbar}{2\pi\cos\left(\frac{kL}{s}\right)}\right]\frac{1}{m} \qquad , k = \frac{2\pi s}{L} \quad (4)$$

L is the wells (the well width), m is the effective electron mass and $\hbar$ is the Planck`s constant.

Since $v_0(r) = \frac{\bar{e}^2}{r}$ and it`s Fourier conversion is $v_0(q) = \frac{2\pi\bar{e}^2}{q}$ superlattice potential (for cosine periodic structure) is equal to:

$$v(q) = v_0 v' = \frac{2\pi\bar{e}^2}{q}\frac{s\hbar}{Lm}\sec\left(\frac{KL}{s}\right) = \frac{2\pi\bar{e}^2}{q} f \quad (5)$$

In which f (the superlattice coefficient) is:

$$f = \frac{s\hbar}{Lm}\sec\left(\frac{KL}{s}\right) \quad (6)$$

This is a sample representing the superlattice potential, which can appear with other coefficients in v_0 .

III. CONDUCTIVITY TENSOR IN TWO-DIMENSIONAL ELECTRON GAS OF A SUPERLATTICE WITH IMPURITY STATES

To calculate the conductivity tensor changes from localized electrons in impure atoms, these effects must be put in two-dimensional plasmon dispersion equation. This contribution of $\delta\sigma$ in the linear approximation to the density of impurities has been shown in the form below:

$$\sigma = \sigma_0 + \delta\sigma \quad (7)$$

σ_0 is conductivity in pure form and it`s known. It`s shown in the following equation in the absence of spatial dispersion:

$$\sigma_0 = \frac{e^2 n_e \tau}{m}\frac{1}{1-i\omega\tau} \quad (8)$$

In which $\nu = \frac{1}{\tau}$ is the electrons collision

Frequency as a result of the impurity scattering potential. In our calculation, the conductivity tensor σ_{ik} is concluded from the Kobo formula:

$$\sigma_{ik}(\vec{q},w) = i\frac{e^2 n_e}{mw}\delta_{ik} + \frac{1}{\hbar w s_0}\int_0^\infty dt e^{iwt}\langle\left[\hat{j}_i(\vec{q},t), \hat{j}_k(-\vec{q},0)\right]\rangle \quad (9)$$

Which $\hat{j}_i(\vec{q},t)$, the Heisenberg - Fourier domain component, is the operator of the two-dimensional electron density. Brackets mean relocation operators and Gibbs angular parentheses are average on position of the impurity atoms[6] and s is the area occupied by electrons. Tensor calculation of the proportion of impurities is:

$$\delta\sigma_{ik}(\vec{q},\omega) = \frac{2ie^2\hbar^2}{m^2 w}\int_{-\infty}^{+\infty}\frac{d^2k}{(2\pi)^2}\int_{-\infty}^{+\infty} d\varepsilon \left(k_i + \frac{q_i}{2}\right)\left(k_k + \frac{q_k}{2}\right) + \delta\rho\left(\vec{k}+\vec{q},\varepsilon\right)[f(\varepsilon) - f(\varepsilon_l)] \times [(\varepsilon - \varepsilon_k + \hbar\omega + io)^{-1} + (\varepsilon - \varepsilon_k - \hbar\omega + io)^{-1}] \quad (10)$$

In which $\vec{k}$ is electron was function and ε_k is the electron energy. In the absence of spatial dispersion $(q = 0)$ we will have:

$$Re\delta\sigma(\omega) = \frac{e^2 r n_i}{\hbar^4\omega^3}\theta(\varepsilon_l + \hbar\omega)[f(\varepsilon_l) - f(\varepsilon_l + \hbar\omega)] + (\omega \to -\omega) \quad (11)$$

$$Im\delta\sigma(\omega) = \frac{e^2 r n_i}{\pi\hbar^4\omega^3}(\varepsilon_l + \hbar\omega)\ln\left[\frac{\varepsilon_F - \varepsilon_l - \hbar\omega}{\varepsilon_F - \varepsilon_l}\right] + (\omega \to -\omega) \quad (12)$$

In which ε_F is the two-dimensional electron gas in the superlattice. For each degree of degeneration of electrons in equation (11) and in (12) for the temperature $(T = 0)$ is acquired. The real part of the dynamic conductivity (11) has the threshold in $\omega_g = \left(\frac{\varepsilon_l}{\hbar}\right)$.

Activation of electrons localized in the field of electromagnetic waves near the threshold is $Re\delta\sigma(\omega) \sim (\omega - \omega_g)$.It gets to the maximum amount with increasing frequency function (11) and then it decreases and this reduction is under the law of ω^{-2}, so we can have the following equation:

$$\frac{\left[\mathrm{Re}\,\delta\sigma(\omega)\right]_{\max}}{\sigma_0} = \psi_{\max}\frac{e^2 n_i r}{\pi\hbar^3\omega_g{}^2\sigma_0} \quad (13)$$

hence:

$$\psi(x) = \frac{\pi\hbar^3\omega_g{}^2}{e^2 n_i r}\mathrm{Re}\,\delta\sigma(\omega) \quad (14)$$

It seen that the real part of $\psi(x)$ has maximum in points where $\omega_g = \frac{|\varepsilon_l|}{\hbar}$ when ($T \neq 0$) and the threshold in points $\omega_g + \frac{\varepsilon_F}{\hbar}$ accordance to the Pauli principle. In equation (13), $\sigma_0 = \frac{ne^2\tau}{m}$ ($\sigma_0 = 2848001111$) is the share of standard two-dimensional electron gas and τ is the mean free average of electrons and according to the amount of $\psi_{\max} \approx 0.41$, $\frac{n_i}{n_e} = 0.5$ and $\tau\omega_g = 10$, $\frac{\varepsilon_f}{\hbar\omega_g} = 0.5$, $\frac{\hbar\omega_g}{k_B T} = 10$ for this proportion, the amount of 0.24% will be obtained if the following typical parameter values are chosen for a superlattice:

$m = 10^{-31} kg$, $|\varepsilon_l| = 10^{-2} eV$, $\frac{n_i}{n_e} = 0.5$, $\frac{v}{\hbar\omega_g} = 0.1$

So the maximum proportion (11) to static conductivity is: $\frac{n_e e^2}{mV} = (\delta_0 = 284800111)$ Which equal to 0.24%

IV. CONCLUSION

In two-dimensional superlattice, the energy spectrum of electrons in which individual and collective forms are motivated by the arrival of impurities was widely investigated. Impurities caused localized electrons. In calculating the conductivity tensor of two-dimensional systems, some properties have appeared which can`t be seen in solid systems and it includes the conductivity changes. Threshold behavior of the real part of conductivity tensor can be seen.

The proportion of conductivity tensor changes in presence of localized levels to a spatial case of conductivity tensor (net increase) indicates 0.24%. These changes will consequently cause changes in the current density and other electrical parameters. Numerical calculations for the two-dimensional superlattice structure GaAs – GaAlAs have been carried out.

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