Spin-orbit interaction effects on the magnetoplasmon spectrum of modulated two-dimensional electron gas

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Abstract

We present a theoretical study of magnetoplasmon spectrum of a two-dimensional electron gas in the presence of Rashba spin-orbit interaction (RSOI), one-dimensional weak electric modulation and a perpendicular magnetic field. The intra-Landau-band magnetoplasmon spectrum is determined in the presence of spin-orbit interaction within the self consistent field approach at finite temperature. Due to Rashba effect, the spin of finite-momentum electrons feels a magnetic field perpendicular to the electron momentum in the inversion plane. The magnetoplasmon spectrum of the modulated two-dimensional electron gas (M2DEG) system is found to exhibit beating of Weiss oscillations due to Rashba effect which is the focus of this work. This effect is absent in the magnetoplasmon spectrum of M2DEG if Rashba spin-orbit interaction is not taken into account. In addition, our finite temperature theory facilitates analysis of effects of temperature on the magnetoplasmon spectrum of M2DEG in the presence of RSOI. We find that the beating pattern is damped but continues to persist at a finite but low temperature.
I. INTRODUCTION

There continues to be a great deal of interest in the investigation and manipulation of the spin degree of freedom of the charge carriers in semiconductor heterostructures with possible applications in the emerging field of spintronics. Spintronics is based on manipulation of the spin degree of freedom of the carriers in order to develop functional mesoscopic devices with wide ranging applications, such as spin filters, spin field effect transistors, field effect switches, data storage, quantum computing and even biological sensors. The manipulation of the spin degree of freedom requires that we have control over the strength of spin-orbit interaction that couples the orbital motion of the electrons with the orientation of electron spins. It was first proposed by Bychkov and Rashba that in the presence of Rashba spin-orbit interaction (RSOI), that arises as a result of structural inversion asymmetry, the spin of finite momentum electrons feels a magnetic field perpendicular to the electron momentum in the inversion plane. Both experimental as well as theoretical studies have shown that RSOI has an important role in semiconductor spintronic systems, since the strength of RSOI can be controlled by applying a gate voltage on top of the two-dimensional electron gas (2DEG).

In addition to the investigation of single particle properties in the presence of RSOI, there is also serious effort to examine the effects of RSOI on the collective properties of semiconductor heterostructures. Single particle magneto-oscillatory phenomena such as the Shubnikov-de Haas and de Haas-van Alphen effects have been important in probing the electronic structure of solids. Their collective analog yields important insights into collective phenomena. In a 2DEG, collective excitations are induced by electron-electron interactions. These collective excitations (plasmons) are among the most important electronic properties of a system. In the presence of an external magnetic field, these collective excitations are known as magnetoplasmons. Magnetic oscillations of the plasmon frequency occur in a magnetic field. In this regard, there have been recent studies of collective excitations (plasmons) of two-dimensional electron gas (2DEG) systems realized in semiconductor heterostructures in the presence of RSOI with and without an external magnetic field. These studies show that the presence of RSOI mixes the spin up and spin down states of neighboring Landau levels with the result that two new, unequally spaced branches arise.

Given the importance RSOI has acquired, it is important to investigate the effects of
RSOI on the magnetoplasmons of a modulated 2DEG. In the absence of RSOI but as a result of modulation, Weiss oscillations in the magnetoplasmon spectrum appear. These oscillations are due to the commensurability of two characteristic length scales of the system: the cyclotron diameter at the Fermi level and the period of the electric modulation. Weiss oscillations are distinctly different from the Shubnikov-de Hass (SdH) oscillations that appear at higher magnetic field strengths. The period of Weiss oscillations depends on both the modulation period and the square root of the number density of the 2DEG, in contrast to the linear dependence on the number density of the SdH oscillations. Moreover, the amplitude of Weiss oscillations is weakly affected by temperature as compared to SdH oscillations. Theoretical study of RSOI effects on single particle quantum transport in a modulated 2DEG was recently carried out, where modulation leads to the broadening of the levels of two unequally spaced branches into bands whose widths oscillate as a function of magnetic field. Furthermore, recently RSOI effects on magnetoplasmon excitations without modulation have been addressed but RSOI effects on commensurability oscillations in magnetoplasmons of a M2DEG have not been discussed so far. This is the subject of the present paper. The present work examines RSOI effects on the collective excitations (magnetoplasmons) of a modulated 2DEG. This investigation is performed within the self-consistent-field approach at finite temperature. We analyze the dynamic, nonlocal dielectric function of the system and highlight the modulation-induced effects on the intra-Landau band magnetoplasmon spectrum in the presence of RSOI. In addition, our finite temperature theory facilitates analysis of effects of temperature on the magnetoplasmon spectrum of a M2DEG in the presence of RSOI as there is an apparent gap in the literature regarding finite temperature effects on the magnetoplasmon spectrum of a M2DEG even in the absence of RSOI. We expect experimental studies such as inelastic light scattering and spectroscopic measurements of magnetoplasmons spectrum of a modulated system in the presence of RSOI would allow verification of the model presented here and would be quite revealing as they pertain to spin-orbit interaction effects on the many-body properties of a 2DEG.
II. FORMULATION

Our system is a modulated two-dimensional electron gas (M2DEG) in the presence of an external magnetic field and RSOI. The magnetic field is applied perpendicular to the $x - y$ plane in which electrons with unmodulated areal density $n_D$, effective mass $m^*$ and charge $-e$ are confined. The Hamiltonian of this system is written as $H = H_0 + H'$, where $H_0$ is the unmodulated and $H'$ the modulation term. We employ the Landau gauge and write the vector potential as $A = (0, Bx, 0)$. The two-dimensional Schrodinger equation in the Landau gauge is\[13, 19];

$$H_0 = (\hat{\mathbf{p}} + e\hat{A})^2 \frac{2m^*}{\hbar^2} + \frac{\alpha}{\hbar} [\hat{\sigma} \times (\mathbf{p} + e\mathbf{A})_z] + \frac{1}{2} g\mu_B B\sigma_z,$$

where $\hat{\mathbf{p}}$ is the momentum operator of the electrons, $g$ the Zeeman factor, $\mu_B$ the Bohr magneton, $\hat{\sigma} = (\sigma_x, \sigma_y, \sigma_z)$ the Pauli spin matrices, $\alpha$ the strength of the RSOI with $H' = V_0 \cos(Kx)$.\[2\]

$K = 2\pi/a$, with $a$ the period of modulation and $V_0$ the amplitude of modulation. Since the Hamiltonian does not depend on the $y$ coordinate, the unperturbed wavefunctions are plane waves in the $y$-direction. This allows us to write for the wavefunctions,

$$\phi_{nk_y}(\bar{x}) = \frac{1}{\sqrt{L_y}} e^{ik_y y} \sum_{n=0}^{\infty} u_{n,k_y}(x + x_0) \begin{pmatrix} C_n^+ \\ C_n^- \end{pmatrix},$$

with $L_y$ being the normalization length in the $y$-direction and $\bar{x}$ a 2D position vector on the $x$-$y$ plane, $x_0 = l^2 k_y = \frac{h k_y}{m^* \omega_c}$, is the coordinate of cyclotron orbit center and $l = \sqrt{\frac{\hbar}{eB}}$ is the magnetic length, $m^*$ is the effective mass. In the $x$-direction, the Hamiltonian has the form of a harmonic oscillator Hamiltonian. Hence, we can write the unmodulated eigenstates in the form $\phi_{nk_y}(\bar{x}) = \frac{1}{\sqrt{L_y}} e^{ik_y y} u_{nk_y}(x; x_0)$, with $u_{nk_y}(x; x_0) = (\sqrt{\pi} 2^n n!)^{-1/2} \exp\left(-\frac{1}{2}\left(x - x_0\right)^2\right) H_n\left(\frac{x - x_0}{\sqrt{\pi} 2^n n!}\right)$, where $u_{nk_y}(x; x_0)$ is a normalized harmonic oscillator wavefunction centered at $x_0$ and $H_n(x)$ are Hermite polynomials with $n$ the Landau level quantum number. The energy of the lowest Landau level is

$$\varepsilon^+_0 = \varepsilon_0 = \frac{1}{2}\hbar\omega_c - g\mu_B B/2$$

with wave function $\phi^+_0(k_y) = \frac{1}{\sqrt{L_y}} e^{ik_y y} u_0(x + x_0)(0)$. For $n = 1, 2, 3, \ldots$ there are two branches of levels, denoted by $+$ and $-$, with energies
$$\varepsilon_n^\pm = n\hbar\omega_c \pm [\varepsilon_0^2 + 2n\alpha^2/l^2]^{1/2}. \quad (5)$$

The + branch is described by the wave function

$$\phi_n^+(k_y) = \frac{1}{\sqrt{L_yA_n}} e^{ik_yy} (D_n u_{n-1}(x+x_0)),$$

and – one by

$$\phi_n^-(k_y) = \frac{1}{\sqrt{L_yA_n}} e^{ik_yy} (-D_n u_n(x+x_0)),$$

where $A_n = 1 + D_n^2$ and $D_n = (\sqrt{2n\alpha/l})/[\sqrt{\varepsilon_0^2 + 2n\alpha^2/l^2}].$

In the presence of modulation, the Hamiltonian is augmented by the term $H'$. In this work, we consider the modulation to be weak such that it is about an order of magnitude smaller than Fermi energy ($V_0 \ll \varepsilon_F$). Hence, we may employ first order (in $H'$) perturbation theory in the evaluation of the energy eigenvalues. The energy eigenvalues in the presence of modulation and taking into account RSOI are

$$\varepsilon_n^\pm(n, x_0) = \varepsilon_n^\pm + V_n^\pm \cos(Kx_0), \quad (6)$$

where $V_n^+ = V_0 e^{-u^2/2}[D_n^2 L_{n-1}(u) + L_n(u)]/A_n$, $V_n^- = V_0 e^{-u^2/2}[L_{n-1}(u) + D_n^2 L_n(u)]/A_n$, $u = \frac{K^2 l^2}{2} = \frac{(2\pi)^2 b}{2n^2\omega_c}$, and $L_n(u)$ is a Laguerre polynomial. The above equation shows that the formerly sharp Landau levels are now broadened into minibands by the modulation potential. Furthermore, the Landau bandwidths oscillate as a function of $n$, since $L_n(u)$ is an oscillatory function of its index. These Landau bands become flat for different values of $B$. Flat bands occur for those values of $B$ for which modulation strength becomes zero. By putting $V_n^\pm = \exp(-\frac{u}{2})[L_n(u) + L_{n-1}(u)] = 0$ one can get the flat band condition using the asymptotic expression

$$\exp(-\frac{u}{2})L_n(u) \simeq \frac{1}{\sqrt{\pi \sqrt{nu}}} \cos(2\sqrt{nu} - \frac{\pi}{4}), \quad (7)$$

$L_n(u) = L_{n-1}(u), and 2\sqrt{u}\{\sqrt{\pi n_D} \mp \frac{a}{\sqrt{2\omega_c}t}\} = \pi(i-1/4),$ with $n_D$ being the electron density, one obtains the following condition

$$2R_c^\pm = a(i - 1/4), \quad i = 1, 2, 3, .......... \quad (8)$$

with $R_c^\pm = R_c^0 \pm \frac{a}{\omega_c}$. $R_c^0$ the cyclotron radius without RSOI, the upper and lower sign corresponds to the ± branch, $R_c^\pm = l\sqrt{2n^\pm} + 1$, is the classical cyclotron orbit. From Eq. (7) it can be observed that, in the large $n$ limit electron bandwidth oscillates sinusoidally and is periodic in $1/B$, for fixed values of $n$ and $a$. When $n$ is small bandwidth still oscillates, but the condition (7) no longer holds because neither eq. (7) nor $L_n(\chi) \simeq L_{n-1}(\chi)$ is valid.
Interestingly, for low values of $B$, when many Landau levels are filled, both the systems have the same flat band condition \[19\].

The dynamic and static response properties of an electron system are all embodied in the structure of the density-density correlation function. We employ the Ehrenreich-Cohen Self-Consistent Field (SCF) approach \[22\] to calculate the density-density correlation function. The SCF treatment presented here is by its nature a high density approximation which has been successful in the study of collective excitations in low-dimensional systems \[10–13, 17, 23, 24\] (semiconductor superlattices and quantum wire structures). Such success has been convincingly attested by the excellent agreement of SCF predictions of plasmon spectra with experiments.

Following the SCF approach, the density-density correlation function of the interacting system can be expressed as

\[
\Pi^\pm(q, \omega) = \Pi^\pm_0(q, \omega) \left( 1 - v_c(q) \Pi^\pm_0(q, \omega) \right)
\]

with $\Pi^\pm_0(q, \omega)$ the density-density correlation function of the non-interacting system, $v_c(q) = \frac{2\pi e^2}{kq}$ the 2-D Coulomb potential, $k$ being the dielectric constant and $q$ is the two-dimensional wave number. Making use of the transformation $k_y \rightarrow -k_y$, with the fact that $\varepsilon^\pm(n, k_y)$ is an even function of $k_y$, and at the same time interchanging $n \leftrightarrow n'$ we write for the non-interacting density-density correlation function appearing in equation (9)

\[
\Pi^\pm_0(q, \omega) = \frac{2m^*\omega_c}{\pi\hbar a} \sum C_{nn'}(x) \int_0^\infty dx_0 [\frac{\omega_c^2}{2}] \left[ f^\pm(\varepsilon(n', x_0 + x_0') - f^\pm(\varepsilon(n, x_0))] \times \left[ \varepsilon^\pm(n', x_0 + x_0') - \varepsilon^\pm(n, x_0) + \hbar\omega + i\eta \right]^{-1}.
\]

In writing the above equation we converted the $k_y$-sum into an integral over $x_0$. $f(\varepsilon(n, x_0))$ is the Fermi-Dirac distribution function, $C_{nn'}(x) = \frac{n_1!}{n_1!} e^{-x} x^{n_1-n_2} [L_n^{n_1-n_2}(x)]^2$ with $x = \frac{\omega_c^2}{2}$, $n_1 = \max(n, n')$, $n_2 = \min(n, n')$, and $L_n(x)$ an associated Laguerre polynomial $x_0 = -\frac{\hbar k_y}{m^*\omega_c}$, and $x_0' = -\frac{\hbar k_y}{m^*\omega_c}$. Without modulation ($V_n^\pm = 0$), the above expression reduces to the result in \[13\].

The above equations (9, 10) will be the starting point of our examination of the intra-Landau band plasmons. These correlation functions are the essential ingredients for theoretical considerations of such diverse problems as high frequency and steady state transport, static and dynamic screening and correlation phenomena.
III. INTRA-LANDAU-BAND PLASMON SPECTRUM IN THE PRESENCE OF RSOI AT FINITE TEMPERATURE

The plasma modes are readily furnished by the roots of the longitudinal plasmon dispersion relation obtained from equation (9) as

\[ 1 - v_c(\bar{q}) \text{Re} \Pi_0^\pm(\bar{q}, \omega) = 0 \]  

along with the condition \( \text{Im} \Pi_0^\pm(\bar{q}, \omega) = 0 \) to ensure long-lived excitations. Equation (11) can be expressed as

\[ 1 = \frac{2\pi e^2}{kq \hbar} \frac{2m^* \omega_c}{\pi a} \sum_{n,n'} C_{nn'} \left( \frac{l_2 \bar{q}^2}{2} \right) \left( I^\pm(\omega) + I^\pm(-\omega) \right), \]  

with

\[ I^\pm(\omega) = P \int_0^a dx_0 \frac{f^\pm(\varepsilon(n, x_0))}{\hbar \omega - \varepsilon^\pm(n, x_0) + \varepsilon^\pm(n', x_0 + x'_0)}, \]  

where \( P \) is the principal value.

The magnetoplasmon modes originate from two kinds of electronic transitions, those involving different Landau bands (inter-Landau band plasmons)\cite{10-13} and those within a single Landau-band (intra-Landau band plasmons). Inter-Landau band plasmons involve the local 1D magnetoplasma mode and the Bernstein-like plasma resonances\cite{25}, all of which involve excitation frequencies greater than the Landau-band separation (\( \sim \hbar \omega_c \)). On the other hand, intra-Landau band magnetoplasmons resonate at frequencies comparable to the bandwidths, and the existence of this new class of modes is due to finite width of the Landau levels caused by the modulation. In order to investigate the effects of RSOI and the modulation on the magnetoplasmon spectrum requires the study of the intra-Landau band magnetoplasmons. In the absence of modulation, the plasmon spectrum of a 2DEG with RSOI has been analyzed in detail elsewhere\cite{10-13} with and without an external magnetic field. In the present work, we investigate the magnetoplasmon spectrum with RSOI in the presence of modulation. We show below that as a result of both modulation and RSOI, Weiss oscillations in the magnetoplasmon spectrum are found to exhibit a beating pattern. This occurs in the low magnetic field regime. At higher fields, Weiss oscillations are suppressed and Shubnikov de Haas (SdH) oscillations are the dominant magnetic oscillations. SdH type of oscillations result from the emptying out of electrons from successive Landau bands when
they pass through the Fermi level as the magnetic field is increased for a fixed value of RSOI. The amplitude of the SdH type of oscillations is a monotonic function of magnetic field, when the Landau bandwidth is independent of the band index $n$. In a M2DEG in the presence of RSOI considered here, the Landau bandwidths oscillate as a function of the band index $n$ which significantly affects the plasmon spectrum of the intra-Landau band type.

For the excitation spectrum, we need to numerically solve equation (12) for all vectors, energies, periodic modulation strength, temperature and magnetic field. We will consider the case of weak modulation ($V_0/E_F <<1$), constant RSOI strength and long wavelength. In this case we are concerned with transitions within a Landau miniband, i.e. $n = n'$, $\varepsilon_{n'}^\pm - \varepsilon_n^\pm = 0$ and $C_{nn'}(x) \to 1^{13}$. Hence, we are able to solve equation (12) analytically at finite temperature.

The intra-Landau-band plasmon dispersion relation at finite temperature reduces to $1 = \sim \omega^2 = \frac{16e^2}{\pi k q \hbar} \times \{ \sin^2(\frac{\pi}{a}(x_0^0)F_n^\pm(u)) \}$, (14)

$$F^\pm(u) = - \sum_n V_n^\pm \times \int_0^{a/2} dx_0 f^\pm(\varepsilon(n, x_0)) \cos(Kx_0)$$ (15)

and $f^\pm(\varepsilon(n, x_0))$ is the distribution function. Without RSOI ($\alpha = 0$) and at zero temperature, this expression reduces to the result obtained in $^{17}$. In the regime of weak modulation

$$f^\pm(\varepsilon(n, x_0)) \simeq f^\pm(\varepsilon_n) + f^\pm(\varepsilon_n)\{V_n^\pm \cos(Kx_0)\}$$, (16)

where $f'(x) = \frac{d}{dx}f(x)$ is the derivative of the Fermi Dirac distribution function. After the substitution of this expansion in equations (14 & 15) and performing the integral over $x_0$, the intra-Landau band spectrum is obtained

$$\hbar^2 \omega^2 = \frac{4e^2 m^* \omega_c}{\pi k q \hbar} \times \{ \sin^2[\frac{\pi}{a}(x_0^0)] \times [G^{++} + G^{--}] \},$$ (17)

here

$$G^{++} = \sum_n |V_n^+|^2 \times [-f^+(\varepsilon_n)] = \sum_n |V_n^+|^2 \times \beta[f^+(\varepsilon_n)\{1 - f^+(\varepsilon_n)\}],$$

and

$$G^{--} = \sum_n |V_n^-|^2 \times [-f^-(\varepsilon_n)] = \sum_n |V_n^-|^2 \times \beta[f^-(\varepsilon_n)\{1 - f^-(\varepsilon_n)\}],$$
where $\beta = K_B T$ with $K_B$ being the Boltzmann constant. Since we have $\Pi^{- -}$ and $\Pi^{++}$, this term leads to an extra negative term for the total intraband correlation[10, 11] $\Pi^{++} + \Pi^{- -}$. The interband correlation is negligible in the long wave length limit because electron spins at the same wave vector in different branches are opposite.

We have derived the expression for $\hbar \tilde{\omega}$ (equation 17) under the condition $\hbar \omega >> |\varepsilon^{\pm}(n, x_0 + x_0') - \varepsilon^{\pm}(n, x_0)|$ as $x_0' \to 0$ which leads to a relation between the energy and the Landau level broadening $\hbar \omega >> |2|V_n^\pm| \{\sin(\frac{\pi}{a_x} x_0') \sin[(\frac{2\pi}{a_x}) (x_0 + \frac{x_0'}{2})]\}|$. This ensures that $\text{Im} \Pi_0(\tilde{q}, \omega) = 0$ and the intra-Landau-band magnetoplasmons are undamped. For a given $|V_n^\pm|$, this can be achieved with a small but nonzero $q_y$ (recall that $x_0' = -\frac{\hbar q_y}{m^* \omega_c}$). In general, the inter- and intra-Landau-band modes are coupled for arbitrary magnetic field strengths. Only the intra-Landau-band mode ($\hbar \tilde{\omega}$) will be excited in the energy regime $\hbar \omega_c > \hbar \omega \sim |V_n^\pm|$.

IV. DISCUSSION OF RESULTS

The intra-Landau-band plasmon energy obtained in equation (17) is shown graphically in Figs (1,2,3) as a function of $1/B$ for different values of the temperature (T) and RSOI parameter : $\alpha = 0$, and $\alpha = 1.2 \times \alpha_0$. The parameters used in all of our figures are $\alpha_0 = 1 \times 10^{-11}$ eVm, $m^* = 0.05 m_e$, $g = 2$, $\mu_B = 5.78 \times 10^{-5}$ eV/Tesla, $k = 14.5$, $n_D = 3.16 \times 10^{-15}$ m$^{-2}$, $a = 380$ nm, and $V_0 = 0.5$ meV. We also take $q_x = 0$ and $q_y = 0.01 k_F$, with $k_F = (2\pi n_D)^{1/2}$ being the Fermi wave number of the unmodulated 2DEG in the absence of magnetic field. Furthermore, in Fig (3) the intra-Landau-band plasma energy is shown as a function of $1/B$ for RSOI strength ($\alpha = 1.2 \times \alpha_0$), temperature T=1K and all other parameters are the same as in Fig. (2). The beating of Weiss oscillations is solely due to + and - branch of the bandwidth of the intra-Landau band plasmon energy satisfying the condition given in Eq. (8). In Fig. (1), we show the intra-Landau band magnetoplasmon spectrum in the absence of spin-orbit interaction $\alpha = 0$ at two different temperatures T=0.25 K, 3.0 K. The minima of Weiss oscillations in Fig. (1) satisfy the flat band condition obtained in Eq. (8) for zero Rashba coupling strength. In this figure, the SdH oscillations are washed out completely at 3K but Weiss persist and are undamped, which confirm the weak dependence of Weiss oscillations on temperature compared to SdH oscillations. To highlight the effects of RSOI, Figs.(2,3) should be compared with Fig.(1). As
a result of finite RSOI, at low magnetic fields (correspondingly higher $1/B$ values) the Weiss oscillations in the intra-Landau band magnetoplasmon spectrum show beating pattern. The minima in Fig. (2 & 3) indicate the individual beats which follow the flat band condition obtained in Eq.(8) with finite value of RSOI strength. This occurs due to the mixing of the spin up and spin down states of neighbouring Landau levels by RSOI resulting in two, unequally spaced levels. The effect of weak electric modulation potential is to broaden these levels into bands. The bandwidth of these bands oscillates as a function of magnetic field. Due to the splitting of the bands, there are two flat band conditions as opposed to a single condition in the absence of RSOI. As a result, there are oscillations at two different frequencies leading to the observed beating pattern. The flat band condition that we arrive at is the same as obtained in [19] and its implications on the transport coefficients are discussed in detail there. The origin of beating pattern in Weiss oscillations can also be understood by a closer analytic examination of Eq. (17) at zero temperature. In the zero temperature case Eq. (17) can be expressed as $\hbar \tilde{\omega} \sim \sqrt{\left| V_n^+ \right|^2 \varepsilon_F + \left| V_n^- \right|^2 \varepsilon_F}$, which is a linear combinations of the two split bandwidths evaluated at the Fermi energy, these are oscillatory functions. They oscillate at different frequencies and their linear combination results in the observed beating pattern of Weiss oscillations.

Furthermore, since the flat band condition depends on the strength of RSOI, the amplitude and phase of the magnetic oscillations (Weiss and SdH) vary with the strength of RSOI. Fig (3) shows the effect of temperature on the magnetoplasmon spectrum while taking into account RSOI. As the temperature is increased from 0.25 K to 1 K, comparing Figs.(2) & (3), we see that the beating pattern in Weiss oscillations of the plasmon spectrum is still present but damped. These results depend on the strength of RSOI as well as the temperature. Consider Eq. (17) at finite temperature $T$. The summations over $n$ can be performed to yield $\hbar \tilde{\omega} \sim \sum_n \sqrt{\left| V_n^+ \right|^2 \times [-f_+^{+(\varepsilon_n)}] + \left| V_n^- \right|^2 \times [-f_-^{-(\varepsilon_n)}]}$. Damping of the plasmon energy with temperature can be explicitly seen if the derivative of the Fermi functions appearing in the above expression are expressed as follows: $-f^{\pm \prime}(\varepsilon_n) = \beta f^{\pm}(\varepsilon_n)\{1 - f^{\pm}(\varepsilon_n)\}$ with $\beta = K_B T$. 
V. CONCLUSIONS

We have determined the intra-Landau band magnetoplasmon spectrum for a modulated two dimensional electron gas in the presence of an external magnetic field and RSOI employing the SCF approach at finite temperature. The magnetoplasmon spectrum of the modulated two-dimensional electron gas system is found to exhibit beating of Weiss oscillations due to Rashba effect as a function of the inverse magnetic field. In the regime of low magnetic field, the modulation induced Weiss oscillations show beating pattern whose period is determined by the period of electric modulation and the strength of RSOI. Furthermore, we find that the beating pattern is damped but continues to persist at a finite but low temperature. Experimental study of these results should be quite revealing as they directly bear on many body properties of modulated 2DEG in the presence of RSOI.

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