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Comment on "Effect of spin-orbit interaction on the plasma excitations in a quantum wire"

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We comment on the recent results [Phys. Rev. B **70**, 235314 (2004)] showing the dispersion relations of single-particle and collective excitations in quantum wires in the presence of the Rashba spin-orbit interaction (SOI). We claim that those calculations performed in the absence of SOI, and used as a strong reference to the interacting case, are unlikely to be correct. We show the correct ω-q plane of the system in the absence of Rashba SOI.

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A recent publication[1] dealt with the frequencies of both plasmon and single-particle excitations in quasi-one dimensional (Q1D) electron gases that experience Rashba spin-orbit interaction (SOI). The electrons in these devices are originally confined in the x-y plane and, due to a further confinement (say in the x direction), they are only free to move along the wire (in the y direction). According to the literature,[2–4] the inversion structure asymmetries in the z direction lead to Rashba SOI. A parameter α is often used to account for such an interaction. Furthermore, the x-direction confinement, which produces the wire and can be assumed of a confining frequency Ω and a localization length λ_0, seems to be responsible for another SOI parameter represented by β.[1,3] Definitions are also assumed such as $l_\alpha \sim \alpha^{-1}$ and $l_\beta \sim \beta^{-1}$ representing spatial length scales associated with α and β couplings, respectively. Different authors found the eigenvalues and eigenstates for this system.[3,4] In particular, Ref. 1 used those which have been calculated in Ref. 3. Within the random-phase approximation (RPA), the plasmon dispersions were then obtained from the usual relation between the induced and the bare electron-electron interactions [Eq. (7)].

This paper comments on Ref. 1 concerning results in the *absence* of Rashba coupling. In particular, Fig. 2 is unlikely to be correct. Readers should be aware that if such a figure is not correct, both the calculations in the *presence* of SOI reported in Ref. 1 and the main conclusions of that paper, which are based on a comparison between Fig. 2 (without SOI) and Fig. 4 (with SOI), are indeed unreliable. Instead of mistaking any assumption either in formulating Eq. (7) or in obtaining its solution, we simply show here the dielectric function, written within the RPA, and used by many authors to obtain the plasmon dispersion relations in Q1D systems in the absence of SOI.[5,6] For the sake of clarity, we plot the ω-q plane which comes out from this dielectric function and claim that the noninteracting figure in Ref. 1 should not contain different physics from that reported before and in Fig. 1 of this paper.

Figure 2 of Ref. 1 shows the zero-temperature ω-q plane for a quantum wire in the total absence of SOI, i.e., for $\alpha = \beta = 0$. It shows intra- and intersubband single-particle excitation (SPE) continua and only one intersubband plasmon mode. Surprisingly, no *intra*subband plasmons show up. These features disagree with what have been shown before in the literature.[5,6] Furthermore, there is no frequency (ω) gap in the intrasubband SPE continuum for finite wave vectors q. We point out that the existence of such a gap is the *main feature* of intrasubband SPEs occurring in *quantum wires*.[6] In the limit of no SOI, the characteristic lengths l_α and l_β tend to infinite. The system then reduces to a spin-degenerate Q1D electron gas, with well-known eigenvalues $E_n(k_y)$ and eigenvectors $\phi_n(x)$.[1,7]

The electronic dielectric function $\varepsilon_{\alpha\beta}(q,\omega)$ for this spin-degenerate system can be obtained within the RPA.[8] It is written as $\varepsilon_{\alpha\beta}(q,\omega) = \delta_{\alpha\beta} - V_{\alpha\beta}(q)\Pi_\beta(q,\omega)$, where $\alpha \equiv (i,i')$ and $\beta \equiv (j,j')$ are the coupled indices with the subband indices i, i', j, and j'. This equation involves the Coulomb electron-electron bare interaction in the 1D geometry, $V_{\alpha\beta}(q)$, and the 1D multisubband irreducible polarizability[5,6]

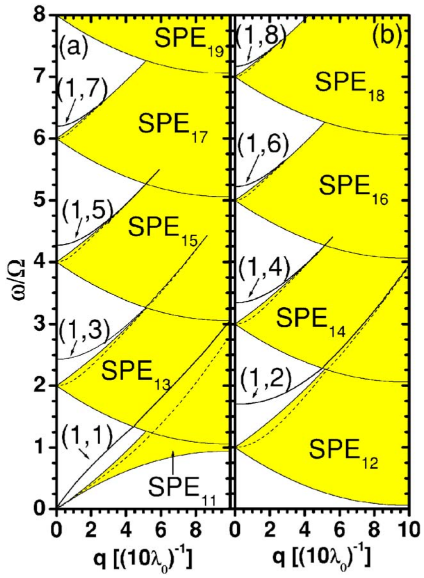

FIG. 1. (Color online) The correct plasmon dispersion relations at zero temperature (solid lines) in the absence of Rashba SOI. Solid lines represent the dispersion relations of the plasmon modes $(1,n)$ as indicated. The shadow regions describe the SPE continua related to the first subband.

$$\Pi_{jj'}(q,\omega) = 2\sum_{k_y} \frac{f_{j'}[E_{j'}(k_y+q)] - f_j[E_j(k_y)]}{E_{j'}(k_y+q) - E_j(k_y) + \omega}. \qquad (1)$$

Here, $f_j(E)$ is the noninteracting Fermi-Dirac distribution function. The factor 2 accounts for the spin degeneracy in Eq. (1).

The symmetry of the confinement potential in the x direction leads to $V_{\alpha\beta}(q)=0$ when $i+i'+j+j'$ is an odd number. As a consequence, the dielectric matrix elements (both the real and the imaginary parts) $\varepsilon_{\alpha\beta}(q,\omega)=0$ for $i+i'+j+j'$ =odd. The dielectric matrix can then be decoupled into two submatrices $\varepsilon_{\alpha\beta}^{\text{even}}(q,\omega)$ and $\varepsilon_{\alpha\beta}^{\text{odd}}(q,\omega)$ with both $i+i'$ and $j+j'$ being even and odd numbers, respectively.[9] We show in Fig. 1 the zero-temperature dispersion relation of the plasmon modes (solid curves) in quantum wires *without* SOI. These modes are given by the zeros of the determinant of the dielectric tensors (a) $\varepsilon_{\alpha\beta}^{\text{even}}(q,\omega)$ and (b) $\varepsilon_{\alpha\beta}^{\text{odd}}(q,\omega)$. We also show the correspondent inter- and intrasubband SPE continua SPE$_{ij}$. These continua are the regions where $\text{Im}[\Pi_{ij}] \neq 0$. We used a 12 subband model with the energy gap $\Omega = 7$ meV. The total electron density is $N_e = 7.0\times10^5$ cm^{-1}. Only one subband is occupied at this density. Dashed lines indicate plasmon modes lying inside the SPE continua. These modes are strongly Landau damped by SPE and are unlikely seen in the experiments. Intersubband plasmon modes $(1,n)$ related to electrons in the first subband are always seen for frequencies $\omega > (n-1)\Omega$. These results agree with seminal works by several authors.[5,6] Note the frequency (ω) gap appearing in the SPE$_{11}$ continuum for finite q and the existence of the intrasubband plasmon (1, 1).

In summary, we have shown that Fig. 2 of Ref. 1 disagrees with what has been published by many authors over the past decades and should not serve as a basis to discuss spin-orbit coupling effects on plasmon excitations in semiconductor quantum wires.

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