Erratum: Gain-assisted superluminal propagation and rotary drag of photon and surface plasmon polaritons [Phys. Rev. A 96, 013848 (2017)]

Naveed Khan, Bakht Amin Bacha, Azmat Iqbal, Amin Ur Rahman, and A. Afaq

A few errors were found in Eqs. (4) and (5) of our article, and those errors affected the numerical results, especially the susceptibility [Fig. 2(a)]. The values of some spectral parameters not mentioned in the paper are also provided in this Erratum.

The corrected Eq. (4), after incorporating the missing plus sign in the denominator of the first term, is as follows:

$$\rho_{ac}^{(2)} = -i\Omega_p \left[\frac{4\Omega_1^2 \left[4(\gamma_{ab} - i\Delta_p)(i\gamma_{bd} + \Delta_p - \Delta_1) - i\Omega_c^2 \right]}{(\Delta_1 - i\gamma_{ad}) \left[4(i\gamma_{ab} + \Delta_p)(i\gamma_{ac} + \Delta_p) - \Omega_c^2 \right] Q} \right.$$
$$\left. + \frac{8\gamma_{ad}(i\gamma_{ab} + \Delta_p)\Omega_1^2}{(\gamma_{ac} + \gamma_{ad})(\gamma_{ad}^2 + \Delta_1^2)(4P + i\Omega_c^2)} \right], \quad (4)$$

where $P = (\gamma_{ac} - i\Delta_p)(i\gamma_{ab} + \Delta_p)$ and $Q = 4(i\gamma_{bd} + \Delta_p - \Delta_1)(-i\gamma_{dc} - \Delta_p + \Delta_1) + \Omega_c^2$.

The unit of gamma (γ) is 1 MHz in terms of which other parameters are defined; see, for example, Ref. [1]. We have selected a moderate value of the probe field's frequency $\nu_p = 1000\gamma$ as in [2]. The central or resonance frequency ω_0 of the probe field is 970γ. In Sec. II of our paper, ν_p and ν_1 are the frequencies of the probe and pump fields, respectively, instead of the phase velocities (as was written mistakenly).
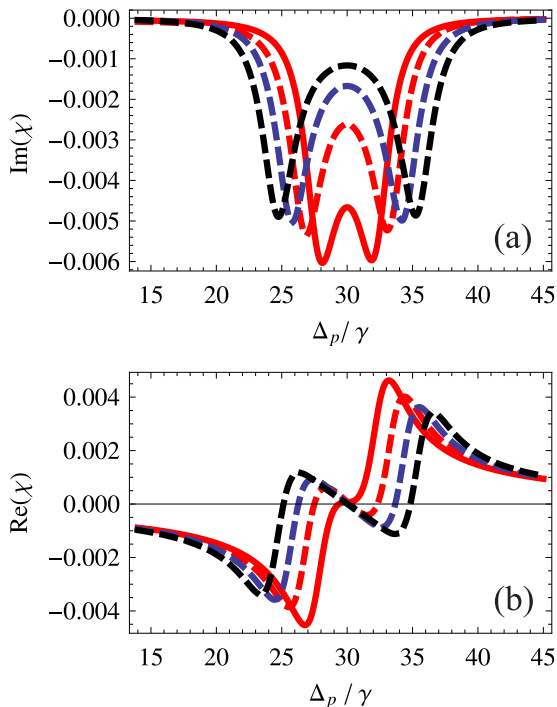
The corrected Eq. (5), after fixing the typing errors, is

$$\chi^{(2)} = \frac{3N\lambda^3}{32\pi^3\Omega_p}\rho_{ac}^{(2)}, \quad (5)$$

where the atomic number density is $N = 5 \times 10^{12}$ cm^{-3}, $\lambda = 2\pi c/\omega$ is the wavelength of the transition between the states a and c, while ω is the corresponding angular frequency. As usual, the susceptibility and group index plotted versus probe detuning have units of $2N|\varrho_{ca}|^2/\epsilon_0\hbar$.

The corrected Eq. (11), after fixing the typing error, is

$$n_g^{sp} = \text{Re}\left(n_r^{sp} + \omega\frac{\partial n_r^{sp}}{\partial\Delta_p}\right). \quad (11)$$

The concepts and conclusions of our original paper regarding the variation in susceptibility, the group index, and the rotary photon drag represented by the drag of light polarization state in the subluminal and superluminal regions remain intact.

The changes in the numerical values of the respective quantities, due to the few corrections and modified parameters, have been reflected in the revised figures in this Erratum. After incorporating the aforementioned changes, the updated plots for the susceptibility, group index, and rotary photon
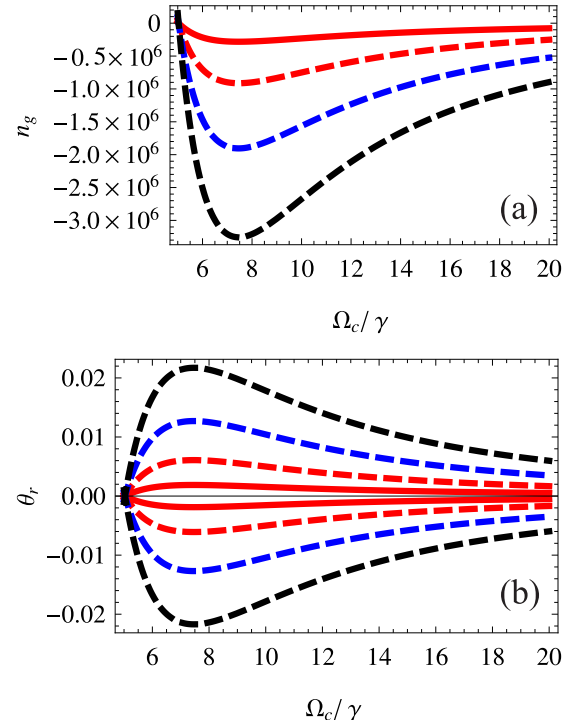

FIG. 2. Variation of (a) imaginary and (b) real part of χ with probe detuning.

FIG. 3. Variation in (a) group index and (b) rotary photon drag with the control field's Rabi frequency Ω_c.
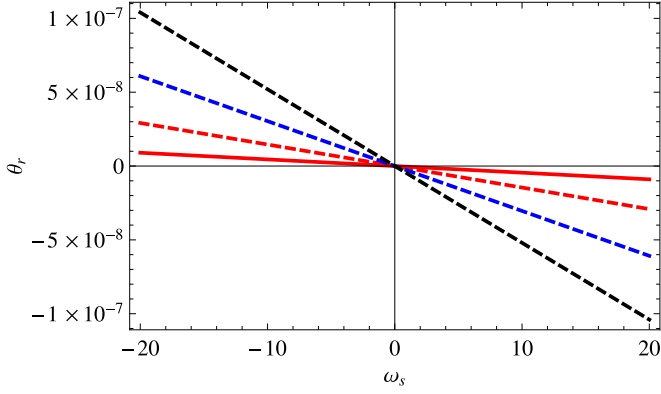
FIG. 4. Dependence of photon drag on the rotation speed of the gain-assisted atomic medium.

drag versus Δ_p/γ at the same spectral parameters of the original article, except for $\omega_0 = 970\gamma$, are shown in the updated Figs. 2–4, respectively. The maximum (negative) value of n_g equals $\sim 3.3 \times 10^6$ [Fig. 3(a)], which manifests superluminal light propagation in the gain-doublet region with a negative group velocity of magnitude 100 m/s. The corresponding photon drag is 0.022 rad. Figure 4 elucidates the variation in photon drag with respect to medium rotation velocity. The maximum value of photon drag is $\sim \mp 10^{-7}$ rad at $\omega_s = \pm 20$ rps.
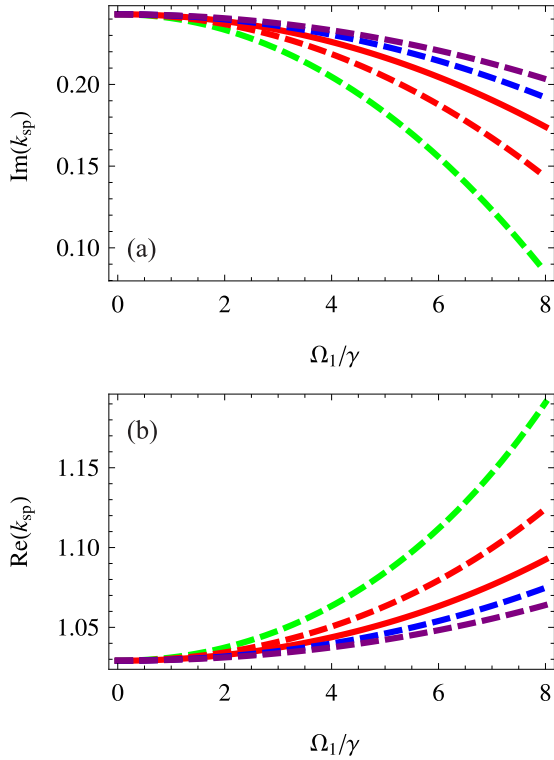

FIG. 5. Variation of (a) the imaginary part and (b) the real part of wave vector k_{sp} for SPPs with Ω_1/γ at fixed parameters: $\gamma_{ac,ad,bd} = 2.5\gamma$, $\gamma_{ab,cd} = 0.5\gamma$, $\mu_0(\mu_m) = 1$, $(\epsilon_0)\epsilon_m = 1$, $\Delta_p = 30\gamma$, $\Omega_c = 7\gamma$ (dashed green line), $\Omega_c = 9\gamma$ (dashed red line), $\Omega_c = 11\gamma$ (solid red line), $\Omega_c = 13\gamma$ (dashed blue line), $\Omega_c = 15\gamma$ (dashed purple line), $\varphi_{1,2,3} = \pi/2$, and $|\sigma| = 2$ S/m.
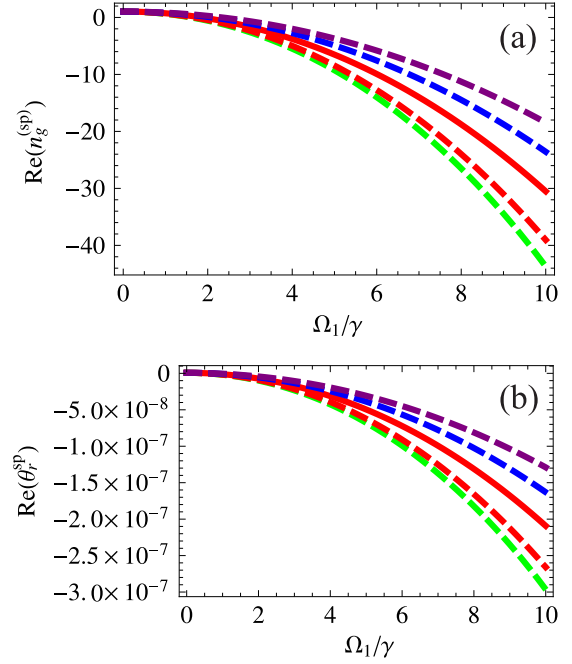

FIG. 6. Impact of Ω_1/γ on group index and the rotary SPP drag with parameters $\gamma_{ac,ad,bd} = 2.5\gamma$, $\gamma_{ab,cd} = 0.5\gamma$, $\mu_0(\mu_m) = 1$, $(\epsilon_0)\epsilon_m = 1$, $\omega_s = 20$ rps, $\Delta_{1,p} = 30\gamma$, $\varphi_{1,2,3} = \pi/2$, $|\sigma| = 2$ S/m, $\omega_0 = 970\gamma$, $\Omega_c = 7\gamma$ (dashed green line), $\Omega_c = 9\gamma$ (dashed red line), $\Omega_c = 11\gamma$ (solid red line), $\Omega_c = 13\gamma$ (dashed blue line), and $\Omega_c = 15\gamma$ (dashed purple line).

The modified convenient spectral parameters are stated in the captions of the corrected Figs. 5–8. It is important to note that we have plotted the physical variables of interest with respect to the pump field's Rabi frequency Ω_c/γ (varying along the x axis) instead of the control field's Rabi frequency Ω_1/γ. As such, the imaginary part of the wave vector k_{sp} of surface plasmon polaritons (SPPs) [Fig. 5(a)], which represents absorption, decreases by increasing Ω_1 (from 0γ to 8γ). However, the real part of k_{sp}, which corresponds to SPP dispersion, increases by increasing Ω_1. Furthermore, the increase in Rabi frequency of the control field Ω_c (from 7γ to 15γ) corresponds to a considerable increase and decrease in the magnitude of absorption and dispersion, respectively.

Figures 6(a), 6(b), 7(a), and 7(b) demonstrate the effect of Ω_1/γ on the SPP group index n_g^{sp} [Eq. (11)] and rotary SPP drag θ_r^{sp} [Eq. (12)] for various values of the control field's Rabi frequency Ω_c at fixed spectral parameters: Δ_p, Δ_1, ω_s, γ_{ij}, σ, and ω_0. Figures 6(a) and 7(a) clearly explicate a noticeable increase in n_g^{sp} by increasing Ω_1 for any fixed value of Ω_c. However, an increase of Ω_c causes a noticeable decrease in n_g^{sp}. The maximum negative value of n_g^{sp} found at $\Omega_c = 7\gamma$ is ~ 43, as shown by a dashed green curve [Figs. 6(a) and 7(a)]. This corresponds to a negative group velocity of $\sim 6.98 \times 10^6$ m/s with $\theta_r^{sp} \sim \mp 3 \times 10^{-7}$ rad [Figs. 6(b) and 7(b)], respectively. The maximum drag coefficient of SPPs predicted by the model is $\sim \mp 3 \times 10^{-7}$ rad [Figs. 6(b) and 7(b)] at $\Omega_1/\gamma = 10$. Moreover, the rotary SPP drag increases with an increase in Ω_c at a particular value of Ω_1. The negative value of SPP drag implies that analogous to photon drag, SPP polarization state rotation also takes place opposite to the rotation of
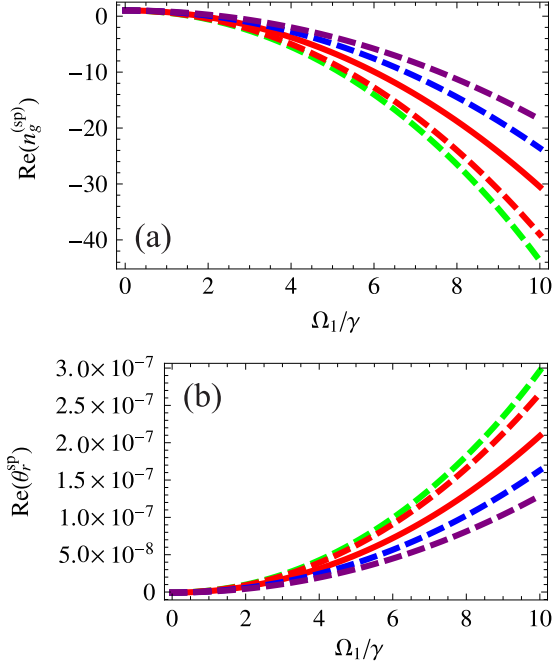
FIG. 7. Variation in the group index and the rotary SPP drag with Ω_1/γ with the parameters $\gamma_{ac,ad,bd} = 2.5\gamma$, $\gamma_{ab,cd} = 0.5\gamma$, $\mu_0(\mu_m) = 1$, $(\epsilon_0)\epsilon_m = 1$, $\omega_s = -20$ rps, $\Delta_{1,p} = 30\gamma$, $\varphi_{1,2,3} = \pi/2$, $|\sigma| = 2$ S/m, $\omega_0 = 970\gamma$, $\Omega_c = 7\gamma$ (dashed green line), $\Omega_c = 9\gamma$ (dashed red line), $\Omega_c = 11\gamma$ (solid red line), $\Omega_c = 13\gamma$ (dashed blue line), and $\Omega_c = 15\gamma$ (dashed purple line).

the atomic-metal interface, which implies superluminal SPP propagation.

Figure 8 shows the dependence of SPP drag on the spin motion of the host medium. For fixed spectral parameters, the
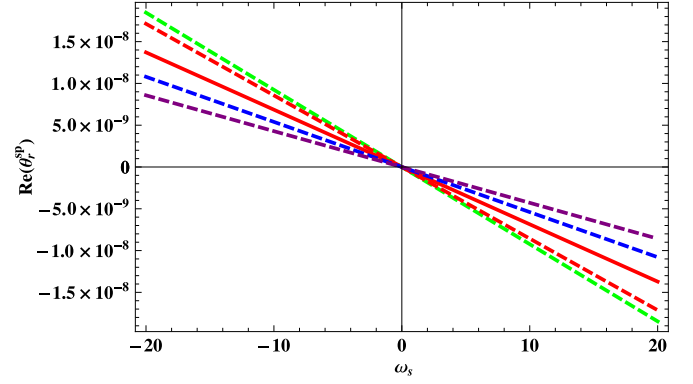

FIG. 8. Dependence of SPP drag on the rotation velocity of the atomic-metal interface and the control field's Rabi frequency such that $\gamma_{ac,ad,bd} = 2.5\gamma$, $\gamma_{ab,cd} = 0.5\gamma$, $\mu_0(\mu_m) = 1$, $(\epsilon_0)\epsilon_m = 1$, $\Delta_1 = 30\gamma$, $\varphi_{1,2,3} = \pi/2$, $\omega_0 = 970\gamma$, $\Omega_1 = 2.5\gamma$, $\Delta_p = 30\gamma$, $|\sigma| = 20$ S/m, $\Omega_c = 7\gamma$ (dashed green line), $\Omega_c = 9\gamma$ (dashed red line), $\Omega_c = 11\gamma$ (solid red line), $\Omega_c = 13\gamma$ (dashed blue line), and $\Omega_c = 15\gamma$ (dashed purple line).

SSP drag coefficient θ_r^{sp} increases with ω_s. In addition, an increase in the control field's Rabi frequency from $\Omega_c = 7\gamma$ (dashed green line) to $\Omega_c = 15\gamma$ (dashed purple line) results in a decrease of θ_r^{sp}. The drag coefficient has a maximum magnitude of $\sim\mp1.8\times10^{-8}$ rad for $\omega_s = \pm20$ rps at the lowest $\Omega_c = 7\gamma$, and a minimum magnitude of $\sim\mp8.6\times10^{-9}$ rad for $\omega_s = \pm20$ rps at the highest $\Omega_c = 15\gamma$ while keeping the other parameters constant.

[1] F. Ghafoor, B. A. Bacha, and S. Khan, Phys. Rev. A **91**, 053807 (2015).

[2] M. Sahrai, H. Tajalli, K. T. Kapale, and M. Suhail Zubairy, Phys. Rev. A **70**, 023813 (2004).