Drag and Drift of Excitons by a Two-Dimensional Electron Current

by **S. K. Lyo**

Motivation—Excitons are a good storage source of light energy and play an increasingly important role in opto-electronic applications. Motion of excitons has been studied for a long time. While desirable, it is very difficult to control the motion of excitons, because excitons cannot be accelerated by an external electric field due to their charge neutrality. We propose a mechanism whereby an exciton gas can be dragged efficiently by an external field into a desired direction with a controllable and significant drift velocity.

Accomplishment—We have demonstrated theoretically that an exciton gas in a two-dimensional quantum-well layer can be dragged by an electric current in an adjacent well over a drift length estimated to be tens of microns during their lifetime of a few nanoseconds. Figure 1 shows this electron-exciton double quantum well structure with a thick center barrier to prevent tunneling. The drag velocity can be a significant fraction (f) of the drift velocity of the electrons, which can be very large for a high-mobility two-dimensional electron gas. For example, for an electron gas with mobility of ten million cm^2/Vsec, with velocity ratio $f = 0.1$, and an applied field of 1 Volt/cm, the drift velocity of the exciton gas can be 10^6 cm/sec, which is much faster than the sound velocity. Figure 2 displays the calculated ratio f of the drift velocities of the exciton and electron gases as a function of the temperature for different electron densities and quantum well parameters. We have also shown that the exciton lifetime and therefore the drift length can be enhanced significantly due to the fact that moving excitons cannot emit photons.

The drag of the excitons is induced by the momentum transfer via monopole-dipole interaction from the electrons in the adjacent QW drifting under an external field. This inter-layer interaction is strong only when the masses of the electron and the hole of the exciton are asymmetric, namely very different as shown in Fig. 2. The inter-layer drag force is balanced by the resistive force applied to the excitons through electron-phonon scattering and interface-roughness scattering. These exciton scattering rates are small at low temperatures and for wide quantum wells, yielding small resistive force and thus large drag ratio f. This drag phenomenon is similar to the well-established Coulomb drag between two electron layers, where the electric current in one layer drags the electrons in the adjacent layer through Coulomb interaction inducing a voltage drop. Another mechanism known so far for dragging excitons is through surface acoustic waves, which drag excitons with the velocity of sound.

Significance—Tools for driving excitons in a given direction with a controllable speed over a long distance are useful in opto-electronic applications. The mechanism we have proposed relies on an external electric field to drag excitons with a speed faster than the sound velocity and enhances the exciton lifetime, yielding an increased exciton drift length. This work was published in Physical Review B **71**, 115317 (2005).

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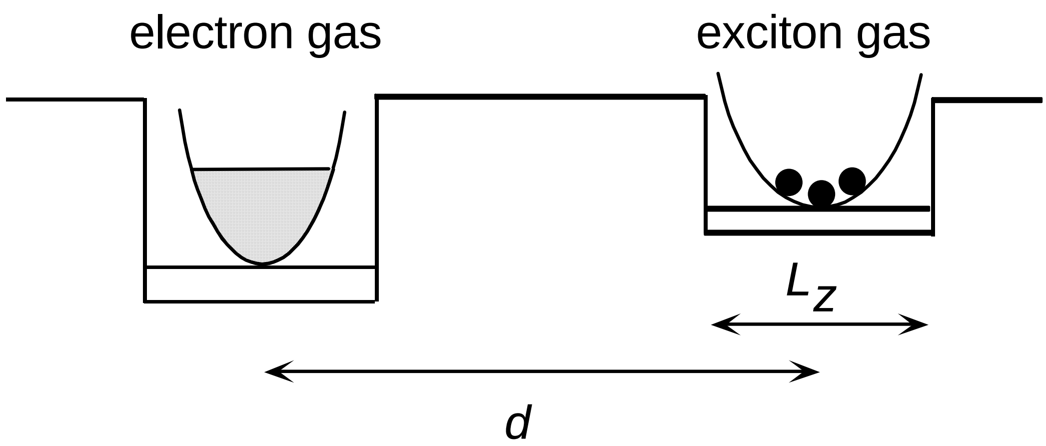

Figure 1. A schematic diagram of a double-quantum-well (QW) structure with an electron gas in the left QW and an exciton gas in the right QW. The two QWs are separated by a wide barrier to prevent tunneling. The quantity d is the center-to-center distance and L_z is the width of the right QW.

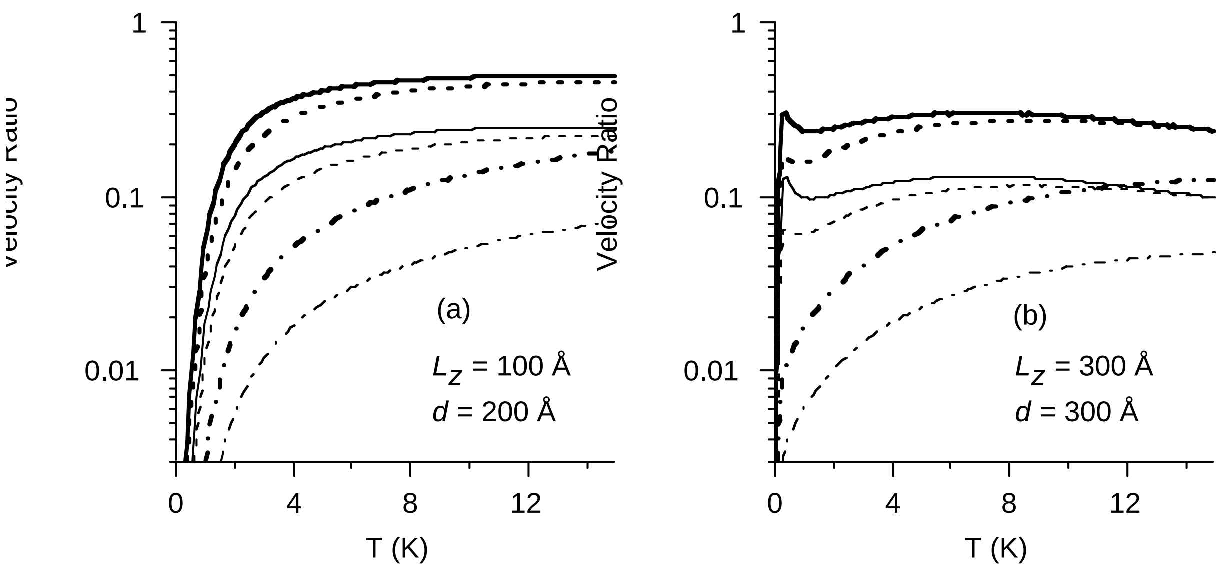

Figure 2. Ratio of the drift velocities of the excitons and the electrons with exciton-phonon and exciton-surface-roughness scattering for two sets of parameters (a) d = 200 Å, L_z = 100 Å and (b) d = 300 Å, L_z = 300 Å for $N_{2D} = 10^{11}$ cm^{-2} (thick curves) and N_{2D} =2310^{11} cm^{-2} (thin curves). The hole mass equals $m_h = 0.45m_o$ (solid curves), $m_h = 0.35m_o$ (dashed curves), and $m_h = 0.14m_o$ (dash-dotted curves). The actual hole mass is (a) $m_h < 0.14m_o$ in the narrow QW and (b) $m_h < 0.45m_o$ in the wide QW.