Comment on "Light-Induced Drift of Quantum-Confined Electrons in Semiconductor Heterostructures"

Stockman, Pandey, and George[1] claim to have predicted a new effect of light-induced drift (LID) of quantum-confined electrons. However, the effect they describe is identical to the photon-drag effect (PDE), observed experimentally in intersubband absorption by a two-dimensional electron gas,[2] and discussed in detail theoretically.[3] We believe the authors were misled by an artificial distinction often made between the LID and the PDE that has led to the existence of two "parallel" literatures on essentially the same subject. In our opinion, the LID can be viewed as a special case of the PDE.

Both effects owe their existence to the momentum of light. Consider optical transitions between the bands $E_i(\mathbf{k}) = E_i^0 + \hbar^2 k^2/2m_i$. In solids, i labels different bands or subbands and, in gases, different atomic states. Figure 1 illustrates absorption of photons of energy $\hbar\omega$ and momentum $\hbar\mathbf{q}$ by particles moving in the directions $\mathbf{q}$ and $-\mathbf{q}$ (respectively, $|\mathbf{k}| = k^{(+)}$ and $|\mathbf{k}| = k^{(-)}$). From the kinematics, $\hbar\omega = E_{21}^0 + \hbar^2 k^2 (m_1 - m_2)/2m_1 m_2 + \hbar^2 \mathbf{k}\cdot\mathbf{q}/m_2$, it follows that if $m_1 \neq m_2$, then both states $k^{(+)}$ and $k^{(-)}$ can be excited and $k^{(-)} - k^{(+)} = 2qm_1/(m_1 - m_2)$. For $m_1 \rightarrow m_2$, only one state is excited: It is either $k^{(+)}$ or $k^{(-)}$, depending on the photon energy.

In general, the PDE results from the motion of the excited particles with the momenta $k^{(+)} + q$ and $k^{(-)} - q$ and of the "holes" left behind at $k^{(+)}$ and $k^{(-)}$. The total current is made up of four components, $J_i^\alpha = eG(k^\alpha)\tau_i(k^\alpha)v_i^\alpha$, where $\alpha \equiv (\pm)$, $\tau_i(k)$ is the momentum relaxation time, $G(\mathbf{k})$ the optical transition rate, $v_1^{(+)} \equiv (\hbar/m_1)k^{(\pm)}$, and $v_2^{(\pm)} \equiv (\hbar/m_2)(k^{(\pm)} \pm q)$. Each of these components is large in the sense that it is proportional to k^α rather than to q, but under "normal" conditions their net sum is small: $\sum_{i,\alpha} J_i^\alpha \sim q$. Nontrivial phenomena arise when the balance between these four currents is destroyed. This happens, generally, when $\tau_1/m_1 \neq \tau_2/m_2$. Two special "resonant" situations can then be distinguished:

$$\tau_2(k) \ll \tau_1(k) \text{ and } \tau_1(k^{(-)}) \ll \tau_1(k^{(+)}) ; \qquad (1)$$

$$G(k^{(-)}) \ll G(k^{(+)}) \text{ or } G(k^{(-)}) \gg G(k^{(+)}) . \qquad (2)$$

Both situations can be realized in transitions between semiconductor valence subbands. An example of case (1) is when the states $k^{(\pm)}$ are close to the optical-phonon energy $\hbar\omega_o$, so that $E_1(k^{(-)}) > \hbar\omega_o > E_1(k^{(+)})$. An example of case (2) (velocity-selective excitation) arises at low temperatures, when the Fermi level lies between the two states: $E_1(k^{(-)}) > E_F > E_1(k^{(+)})$.

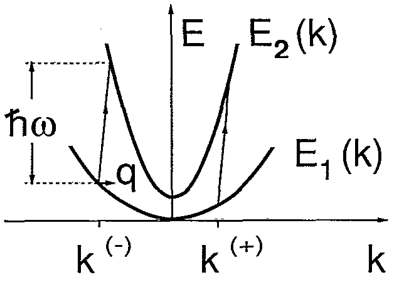

FIG. 1. Illustration of the optical transitions between quantum subbands with account of the photon momentum.

In both special cases, the average particle velocity is of order $\hbar k^{(\pm)}/m \gg \hbar q/m$, and the drag effect is much enhanced. A characteristic feature of the resonant PDE is the dependence of the flux *direction* on the photon energy. This phenomenon was first observed in p-Ge PDE experiments, under conditions corresponding to the "velocity-selective" excitation of type (2), and theoretically discussed for both cases (2) and (1). References to those works can be found in Ref. 3.

A simple realization of case (2) occurs in systems with parallel bands, $m_1 = m_2$ [the requirement $\tau_1 \neq \tau_2$ is usually fulfilled, while inequality (2) is provided by the kinematics of monochromatic excitation], such as electronic subbands in quantum wells and wires, atoms in gases, and Landau subbands in a magnetic field.[4] These systems constitute the subject of studies in the LID literature, where the velocity-selective excitation is usually interpreted in the Doppler-effect language. In the LID literature, including Ref. 1, the PDE is viewed as a small effect, related to LID by a factor q/k. That this is not so in special cases (1) and (2) has been demonstrated above. Hence LID and PDE present different views on the same underlying physics.

A. A. Grinberg and S. Luryi
AT&T Bell Laboratories
Murray Hill, New Jersey 07974

Received 28 January 1991
PACS numbers: 73.20.Dx, 42.50.Vk

---

[1] M. I. Stockman, L. N. Pandey, and T. F. George, Phys. Rev. Lett. **65**, 3433 (1990).

[2] A. D. Wieck, H. Sigg, and K. Ploog, Phys. Rev. Lett. **64**, 463 (1990).

[3] S. Luryi, Phys. Rev. Lett. **58**, 2263 (1987); A. A. Grinberg and S. Luryi, Phys. Rev. **38**, 87 (1988).

[4] The first theoretical discussion of the PDE in transitions between magnetic subbands was presented by L. E. Gurevich and A. Ya. Vinnikov, Fiz. Tverd. Tela **15**, 87 (1973) [Sov. Phys. Solid State **15**, 58 (1973)].