Light-induced dissipationless electron transport in quantum wells

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It is well known that the strong interaction between a solid and a monochromatic electromagnetic field with a frequency ω_0 can open energy gaps $\Delta\varepsilon$ within electron energy bands of the solid due to the dynamical Stark effect [1,2]. These gaps $\Delta\varepsilon$ are opened in the resonant points of $\boldsymbol{k}$ space (i.e., at electron wave vectors $\boldsymbol{k}$ satisfying the condition of "the photon energy $\hbar\omega_0$ is equal to the energy interval between electron bands"). If the electron energy spectrum of the solid is symmetric, $\varepsilon(\boldsymbol{k}) = \varepsilon(-\boldsymbol{k})$, the resonant points — and, correspondingly, the gaps $\Delta\varepsilon$ — are positioned symmetrically in the $\boldsymbol{k}$ space with respect to band edges [see Fig.1(a)]. Though the light-induced gap opening has been known for a long time [1,2], its theory was developed exclusively for solids with such a symmetric electron energy spectrum. It follows from the fundamentals of quantum mechanics that the asymmetric energy spectrum of electrons, $\varepsilon(\boldsymbol{k}) \neq \varepsilon(-\boldsymbol{k})$, can exist in systems with broken time-reversal symmetry. Particularly, it takes place in nanostructures in the presence of a magnetic field. For definiteness, let us consider an asymmetric quantum well (QW) confining electrons in the plane (x,y), which is exposed to an in-plane magnetic field H_y directed along the y axis. It is well-known that the electron energy spectrum of the QW consists of a set of subbands which are shifted along the k_x axis with respect to each other by the wave vector $\Delta k_x \propto H_y$ [3]. This diamagnetic shifting, which is schematically pictured in Fig. 1(b), leads to the asymmetric energy spectrum of electrons, $\varepsilon(k_x) \neq \varepsilon(-k_x)$, in the QW. As a consequence of this asymmetry, resonant points of the intersubband electron-photon interaction are positioned asymmetrically in the $\boldsymbol{k}$ space with respect to subband edges. Correspondingly, the photon-induced energy gaps $\Delta\varepsilon$ are positioned asymmetrically within the subbands. The remarkable feature of such an asymmetrically gapped energy spectrum is the nondissipative flowing of electron gas. For instance, let an electron gas fills states under the Fermi level μ [see Fig. 1(b)]. It is easy to show that the electric current along the x axis, produced by the electron gas, is $j_x \propto \Delta\varepsilon$. Since this nonzero current is associated to the ground state of the electron system, it flows without dissipation. Thus, the photon-dressed electron system with broken time-reversal symmetry can demonstrate the superconductor-like behavior. The theory of this novel quantum phenomenon is developed in the recent papers [4,5] and will be presented in the given talk.

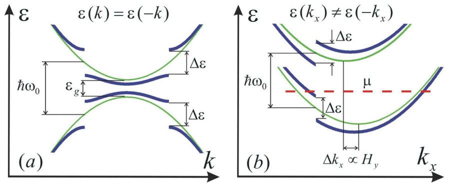

FIG. 1: Energy spectrum of free electrons (thin lines) and electrons dressed by an electromagnetic field with the frequency ω_0 (solid lines): (a) conductivity band and valence band in a bulk semiconductor with the band gap ε_g [2]; (b) first two electron subbands in an asymmetric quantum well exposed to an in-plane magnetic field H_y [5].

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