In-plane stationary current in double-well structure

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We study the in-plane stationary current caused by phototransitions between the states of a quantum well. The electric field of light $\mathbf{E}(t) = \mathrm{Re}\,(\mathbf{E}e^{-i\omega t})$ has both vertical and in-plane components. The stationary current originates from the periodic vibration of electrons between two non-equivalent quantum wells caused by the normal component of the alternating electric field with simultaneous in-plane acceleration/deceleration by the in-plane component of electric field $\mathbf{E}(t)$. First, the classical model of the process is developed. Namely, we consider electrons in the oscillator well in z direction. The classical Newton equation for an electron has the form $\ddot{\mathbf{r}}(t) + \Omega^2\mathbf{n}z(t) + \gamma\dot{\mathbf{r}}(t) = e\mathrm{Re}(\mathbf{E}e^{-i\omega t})/m$, where the liquid friction coefficient $\gamma = \gamma_0 + \gamma_1 z$ is introduced; $\mathbf{n}$ is the unit vector along z-axis. The solution in the first order in γ_1 reads

$$\overline{\dot{\mathbf{r}}(t)} = \frac{\gamma_1 \omega e^2}{2\gamma_0 m^2}\mathrm{Im}\frac{(\mathbf{En})(\mathbf{E}^* - \mathbf{n}(\mathbf{nE}^*))}{(\omega^2 - i\gamma_0\omega)(\omega^2 - \Omega^2 + i\gamma_0\omega)}. \tag{1}$$

Here $\overline{(...)}$ denotes the time averaging. The stationary drift of electron leads to the stationary current $\mathbf{j} = en_s\overline{\dot{\mathbf{r}}(t)}$, where n_s is the surface electron concentration.

The quantum mechanism of the stationary current in double quantum well is conditioned by in-plane transition asymmetry which appears due to the indirect phototransitions with the participation of impurity scattering. Figure a,b and c show the sketch of a proposed experiment, the band structure of the system under consideration, and the scheme of phototransitions. The photocurrent has a resonant character corresponding to the equality of the photon energy to the distance between subbands Δ. The current appears in response to the linear-polarized light. The resulting current for the case of δ-like quantum wells is

$$\mathbf{j} = \frac{e^3 d n_s}{m\Delta}\frac{\tau}{(\Delta-\omega)^2\tau^2 + 1}(\mathbf{E} - \mathbf{n}(\mathbf{nE}))(\mathbf{nE})\frac{d^2}{2z_0^2}\frac{\beta(1-\beta^2)}{(1+\beta^2)^2} \tag{2}$$

Here β is the amplitude of mixing of the states in different wells, d is the distance between wells, τ is the intrawell relaxation time for scattering on Coulomb impurities. Estimates show that the current density in GaAs/GaAlAs structure can achieve maximum 3.6 μA/cm at electric field $E = 1V/cm$.

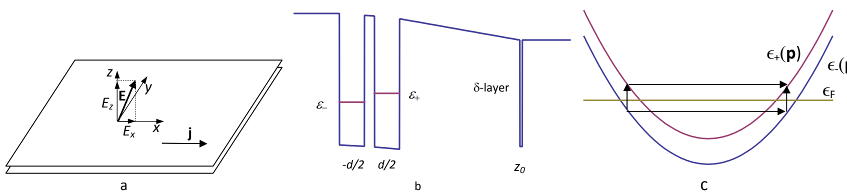

FIG. 1: a) Proposed experiment. The electric field of light $\mathbf{E}(t)$ is tilted in (x,z) plane. The stationary current is directed along the x-axis. b) The band structure. Quantum wells are centered in planes $z = \pm d/2$. The carriers are provided by the δ-layer of donors in the plane z_0. c) The transition amplitude is combined from vertical light-induced transition and impurity scattering non-conserving the in-plane momentum.