Mechanism of giant microwave response of two-dimensional electron system near the second harmonic of the cyclotron resonance

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Remarkable features of microwave (MW) response of high-mobility two-dimensional electron systems (2DESs) at low temperature in magnetic field B have excited much interest the last few years, for review see [1]. Recently in ultraclean 2DESs new phenomenon has been revealed [2, 3, 4, 5]: colossal narrow photoresistivity spike was observed when MW radiation frequency Ω is near the second cyclotron resonance harmonic $2\omega_c$, where $\omega_c = |eB/mc|$, m is electron effective mass. It is significant to note that all 2DESs where the spike occurs show giant negative magnetoresistance in the absence of MW radiation. The origin of the spike is not clear.

We propose an explanation of the spike appearance in terms of classical approach to the description of 2DES. Our explanation is based on the parametric resonance (PR) phenomenon of electron motion caused by spatial inhomogeneous electric field of MW pumping. Such an inhomogeneous field appears due to metal contacts to 2DES near which the incident MW radiation is strongly modified [6]. One can understand the occurrence of PR by an analogy with swings which length varies periodically with frequency Ω. The fundamental mode of PR emerges at double eigenfrequency of the swings. In 2DES in magnetic field one can consider ω_c as eigenfrequency and therefore PR arises at $\Omega \approx 2\omega_c$.

We describe motion 2D electrons with the hydrodynamic velocity $\mathbf{V}$ which depends on coordinates and time and obeys the Euler equation. This equation contains the nonlinear term $(\mathbf{V}, \nabla)\mathbf{V}$ which is significant to our approach. One can examine the term as nonlinear local and instantaneous Doppler shift and this is the term which causes PR. We show that nonlinear correction to velocity $\mathbf{V}$ can grow exponentially over time, i.e. PR realizes, provided the gradient of electric field acting on 2D electrons exceeds threshold value.

We also discuss the spatial structure of the electric field acting on electrons as compared to the electric field of the incident MW radiation. The former field can be much greater as against the latter via the presence of metal contacts and as well as via nonlocal effects. Nonlocal effects emerge due to inhomogeneity of electric field of MW pumping on the electron cyclotron radius R_c scale, where $R_c = v_F/\omega_c$, v_F is the Fermi velocity.

Thereby we show that instability can arise in 2DES provided the gradient of MW electric field acting 2D electrons is greater than the threshold value which likely occurs at $\Omega \approx 2\omega_c$. Instability leads to heating of 2DES which destroys negative magnetoresistance state. This in turn leads to the sharp photoresistivity spike observed in experiments [2, 3, 4, 5].

[1] I.A.Dmitriev, A.D. Mirlin, D.G. Polyakov, and M.A. Zudov, Rev. Mod. Phys., **84**, 1709 (2012).
[2] Ya. Dai, R.R. Du, L.N. Pfeiffer, and K.W. West, Phys. Rev. Lett. **105**, 246802 (2010).
[3] Ya. Dai, K. Stone, I. Knez, C. Zhang, R.R. Du, C. Yang, L.N. Pfeiffer, and K.W. West, Phys. Rev. B **84**, 241303(R) (2011).
[4] A.T. Hatke, M.A. Zudov, L.N. Pfeiffer, and K.W. West, Phys. Rev. B **83**, 121301(R) (2011).
[5] A.T. Hatke, M.A. Zudov, L.N. Pfeiffer, and K.W. West, Phys. Rev. B **83**, 201301(R) (2011).
[6] S.A. Mikhailov and N.A. Savostianova, Phys. Rev. B **74**, 045325 (2006).