Mechanisms of Absolute Negative Conductivity in a Two-Dimensional Electron Gas Stimulated by Microwave Radiation and Zero-Resistance States

Victor Ryzhii[1], **Robert Suris**[2], **and Bagun Shchamkhalova**[3]

[1] *Computer Solid State Physics Laboratory, University of Aizu, Aizu-Wakamatsu 965-8580, Japan*
[2] *A. F. Ioffe Physical-Technical Institute, Russian Academy of Sciences, St. Petersburg 194121, Russia*
[3] *Institute of Radio-Engineering and Electronics, Russian Academy of Sciences, Moscow 141190, Russia*

The effect of vanishing of electrical resistance in a two-dimensional electron gas (2DEG) in magnetic field irradiated with microwaves has recently been observed by Mani *et al.* [1] and Zudov *et al.* [2]. Anderson and Brinkman suggested [3] that the effect can be attributed to a specific behavior of 2D electrons in magnetic field subjected to electromagnetic excitation at a frequency ω somewhat higher that the cyclotron frequency ω_c and at frequencies above the harmonics of ω_c. Indeed, as predicted theoretically by one of the present authors more that 30 years ago [4] (see also Ref. [5]), the photocurrent associated with impurity scattering stimulated by microwaves in a 2DEG in the magnetic field $\mathbf{H} = (0, 0, H)$ perpendicular to the 2DEG plane and the net in-plane electric field $\mathbf{E} = (E_x, E_y, 0)$ can be directed opposite to the electric field if $(\omega - N\omega_c) \simeq eE/\hbar > 0$. Here $N = 1, 2, 3, ...$, $e = |e|$ is the electron charge, $E = |\mathbf{E}|$, $L = \sqrt{c\hbar/eH}$ is the quantum Larmor radius, c is the velocity of light, and $\hbar$ is the Planck constant. As a result, the transverse diagonal (dissipative) component of the 2DEG conductivity tensor $\sigma(E)$ can become negative (the so-called effect of absolute negative conductivity). Contrary, when $(\omega - N\omega_c) \simeq -eEL/\hbar < 0$, the pertinent component of the conductivity tensor is positive. However, the probability of the scattering with the spatial displacements of the electron Larmor orbit center $\xi = \hbar(\omega - N\omega_c)/eE$ exceeding the quantum Larmor radius is exponentially small. Due to this, such scattering processes become effective, and the variation of the dissipative component of the current caused by microwave radiation (i.e., the photocurrent) can be substantial only in sufficiently strong electric fields. Therefore, the role of other scattering mechanisms, for example the photon-assisted acoustic piezoelectric scattering, should be assessed.

The purpose of this communication is to remind the mechanisms of absolute negative conductivity in a 2DEG in crossed electric and magnetic field stimulated by microwave radiation (associated with the photon-assisted scattering on impurities and optical phonons) and consider some other mechanisms. In particular, we demonstrate that the photon-assisted electron scattering on acoustic phonons can result in the absolute negative conductivity at low electric fields in rather wide ranges: $N\omega_c < \omega < (N+1)\omega_c$. In the case of this mechanism, the spatial displacements of the electron Larmor orbit center is determined not only by ω and ω_c, but by the energy of the emitted or absorbed acoustic phonon $\hbar\omega_q$ as well, so that $\xi = \hbar(\omega - N\omega_c \pm \omega_q)/eE$. This can lead to high probabilities of the electron Larmor orbit center hops even at relatively large $|\omega - N\omega_c|$ and fairly small E. Apart from a dynamic effect of microwave radiation, the absolute negative conductivity can appear due to the electron heating, much as it was considered previously [6] for a nonequilibrium 2DEG [6,7].

We also discuss the possible role of the mechanisms of absolute negative conductivity in the formation of the zero-resistance states. The dependences of the net dissipative current

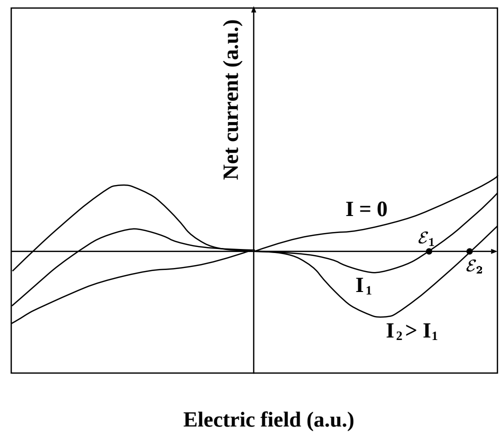

Figure 1: Qualitative view of net dissipative current vs electric field at different intensities of microwave radiation ($I = 0, I_1, I_2$).

(including the dark current and the current stimulated by microwave radiation) on the electric field at different intensities of microwave radiation are schematically shown in Figure 1. Thus, at sufficiently high intensities of microwave radiation with a proper frequency, the dissipative conductivity is negative in some range of the electric fields. The scenario under consideration assumes that the zero-resistance states correspond to stable spatial distributions of the electric field in the 2DEG. We consider the stability of uniform states with different values of E and, hence, different currents (and resistances). In particular, we show that the states with $E \geq \mathcal{E}$ in the bulk of a 2DEG system, where $\mathcal{E}$ satisfies the equation $\sigma(\mathcal{E}) = 0$ (see Fig. 1), are stable, while such states become unstable when $E < \mathcal{E}$. The states with $E = \mathcal{E}$ can be referred to as "dissipationless" states because the Joule power $P = \mathbf{jE}$ turns to zero due to $\sigma(\mathcal{E}) = 0$.

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