Radiation-induced magnetoresistance oscillations in two-dimensional electron systems

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We carry out a systematic theoretical analysis on radiation induced magnetoresistance oscillations (RIMO) in high-mobility two-dimensional electron systems (2DES) [1-5], based on the balance-equation approach to magnetotransport developed for high-carrier-density systems [6]. The time-dependent drift velocity \( v(t) \) and electron temperature \( T_e \) serve as the basic parameters, which enter the frictional force, energy absorption and energy dissipation rates and are determined through the force and energy balance equations when the incident radiation field is given. The model covers regimes of inter- and intra-Landau level processes, takes account of multiphoton-assisted electron transitions as well as radiation-induced change of the electron distribution, and naturally includes electrodynamic damping. Electron scatterings by impurities, transverse and longitudinal acoustic phonons as well as polar optic phonons are considered simultaneously.

When a slowly varying electric field \( E_0 \) and a high frequency (HF) field \( E(t) = E_0 \sin(\omega t) + E_0 \cos(\omega t) \) are applied in a quasi-2D system consisting of \( N_e \) interacting electrons in a unit area of the \( x-y \) plane, together with a magnetic field \( B = (0, 0, B) \) along the \( z \) direction, the time-dependent drift velocity \( \mathbf{v}(t) = v_x \cos(\omega t) + v_y \sin(\omega t) \), and electron temperature \( T_e \) satisfy the following force and energy balance equations:

\[
m \frac{dv_0}{dt} = eE_0 + e(v_0 \times B) + \frac{F_0}{N_e},
\]

\[
N_e E_0 \cdot v_0 + S_p - W = 0,
\]

The magnetoresistivity is \( R_{zz} = -\frac{F_0}{N_e v_0} (\frac{N_e^2 e^2 v_0^2}{\hbar}) \).

Under the influence of a modest irradiation of frequency \( \omega \) in the submillimeter wave range, the low-temperature \( (T \sim 1 \text{K}) \) magnetoresistance of the 2DES as a function of the magnetic field, obtained from the above equations, exhibits strongly oscillating peak-valley structures around \( \omega / \omega_c = j \), i.e. a maximum at \( \omega / \omega_c = j - \delta_j^- \), a minimum at \( \omega / \omega_c = j + \delta_j^+ \) with a node at \( \omega / \omega_c = j (j = 1, 2, 3, 4, \ldots) \), \( \delta_j^\pm = 0.1 - 0.25 \), \( \omega_c \) is the cyclotron frequency. The energy absorption rate \( S_p \) of the electron system exhibits a large main peak at cyclotron resonance \( \omega / \omega_c = 1 \) and smaller peaks at \( \omega / \omega_c = 2, 3, 4, \ldots \), resulting in the electron temperature \( T_e \) oscillating in a similar fashion.

This essentially quantitative theoretical model not only reproduces the main features of RIMO, predicts the appearance of the measured zero resistance, but also explains the other prominent experimental observations, including: (1) rapid diminution of RIROs by a few degree rise of temperature [6]; (2) remarkable amplitude modulation of SdH oscillations [7]; (3) additional peak-valley structures at \( \omega / \omega_c = 1/2, 2/3, 3/2 \) due to multiphoton processes under enhanced radiation [8]; (4) strong suppression of the average dissipative resistance by the irradiation [8]; (5) why RIMO do not appear in lower mobility samples; (6) why RIMO are unlikely to show up in 2D hole systems; (7) what may happen when the radiation frequency higher than 0.2 THz; (8) new peak-valley pairs and zero-resistance states under bichromatic radiation.

The calculated \( R_{zz}, T_e \), and \( S_p \), for a 2DES subjected to 280 GHz radiations of different strengths, and the calculated photoresistance \( \Delta R_{zz} = R_{zz} - R_{zz}(w/o \text{ rad}) \) for a 2DES subjected to radiations having same strength \( E_0 = 3 \text{ V/cm} \) but different frequencies from 80 to 250 GHz, are shown in the following figures.

References:

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