Nonlinear transport in GaAs heavily doped quantum wells at large filling factors

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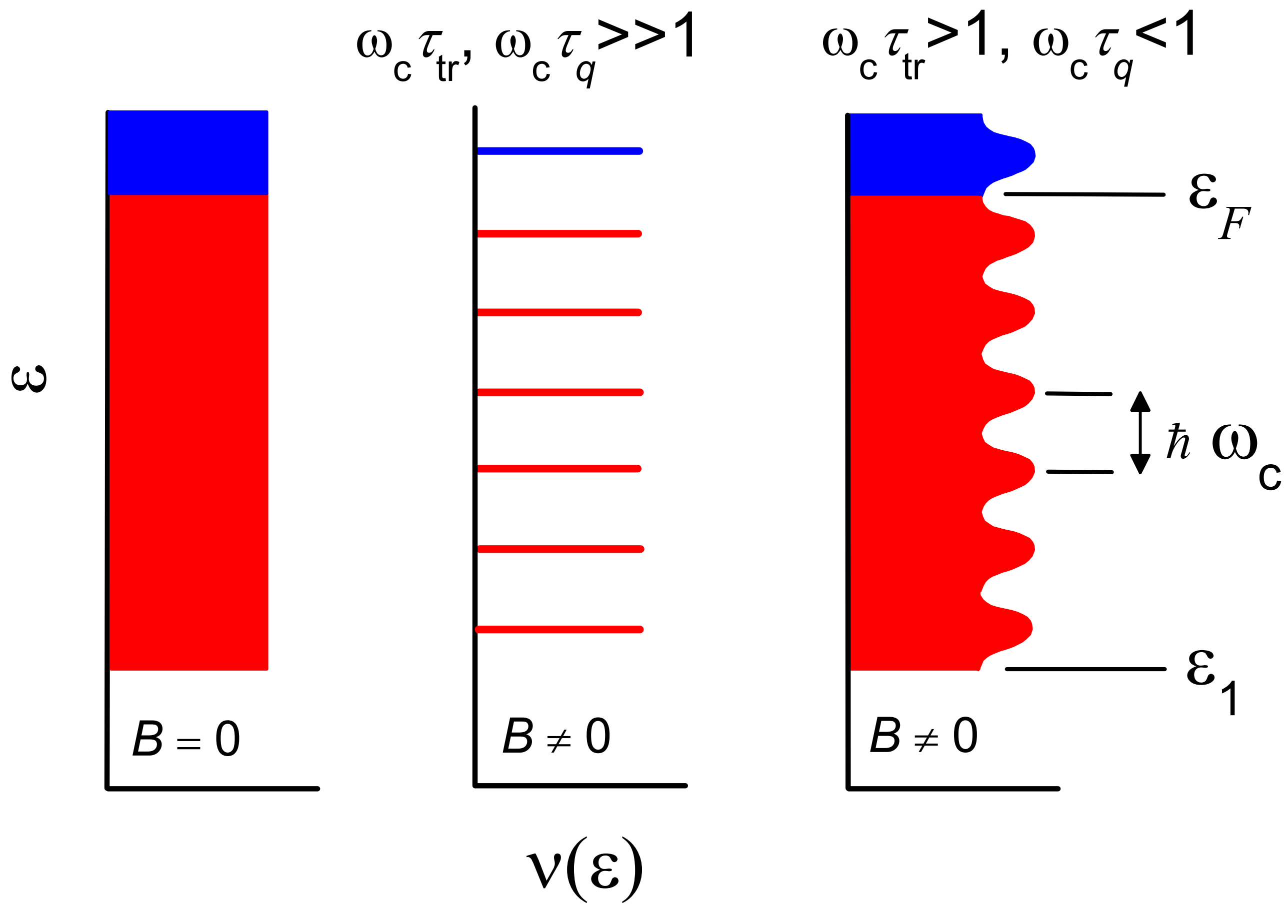
Outline

1. Introduction
2. Experiment
3. Results
4. Conclusion

Работа проводилась при финансовой поддержке РФФИ

1. Introduction

$$\varepsilon_F \gg \hbar\,\omega_c$$

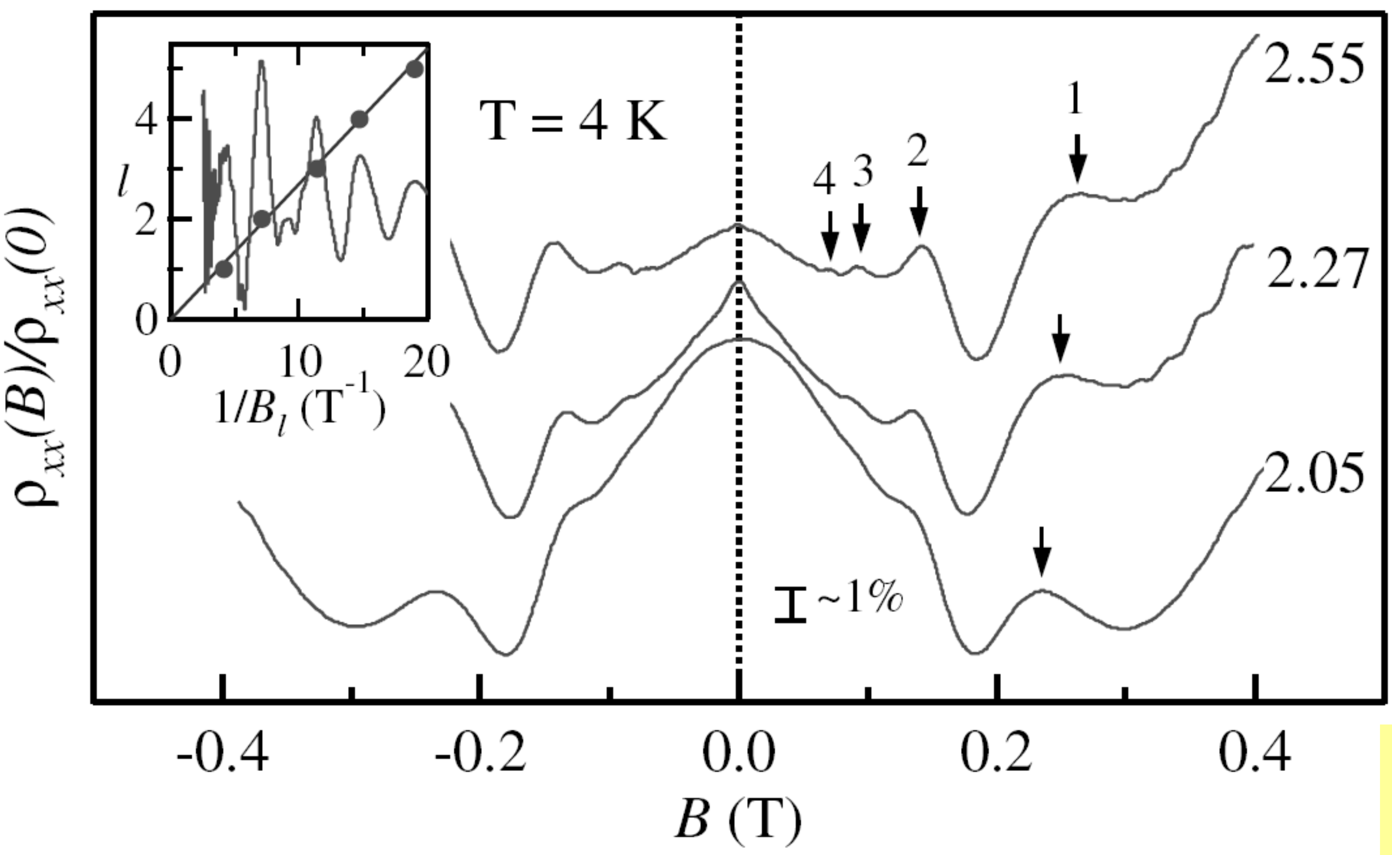


$$\sigma_{xx} = \int \sigma_{dc}(\varepsilon)[-\partial_\varepsilon f_T(\varepsilon)]d\varepsilon$$

Phonon-Induced Resistance Oscillations

(PIRO, ω_S/ω_c - oscillations)

M. A. Zudov et al.
PRL, **86**, 3614 (2001)



$$2k_F u_S = l\omega_c$$

FIG. 1. $\rho_{xx}(B)/\rho_{xx}(0)$ traces (shifted vertically for clarity) are shown for three densities n_e of 2.05, 2.27, and 2.55 $\times 10^{11}$ cm^{-2}, respectively; arrows indicate the maxima for $l = 1, 2, 3, 4$ and the shift of the primary ($l = 1$) peak with increasing n_e. Inset shows that the oscillations are periodic in $1/B$.

Microwave-Induced Resistance Oscillations

(MIRO, ω/ω_c - oscillations)

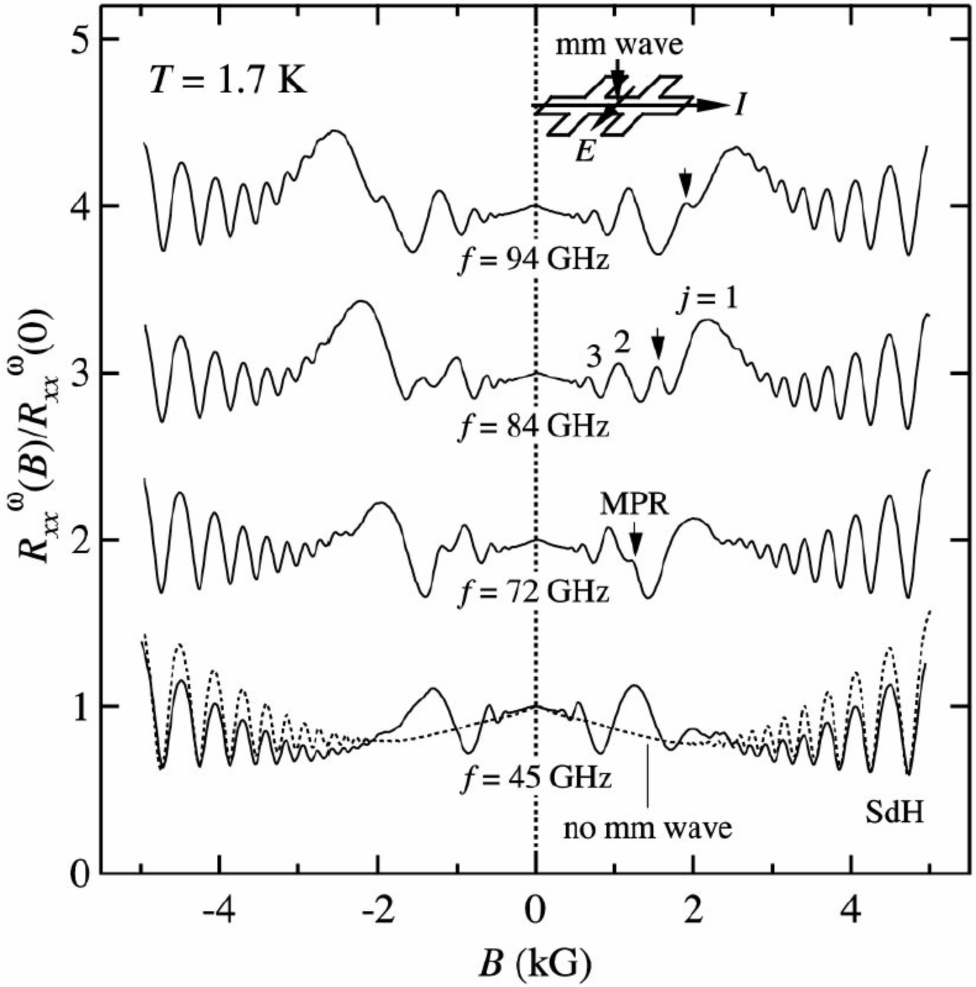


FIG. 1. Normalized magnetoresistance from 200 μm Hall bar with millimeterwave illumination on (solid lines) and off (dotted line) for selected frequencies. The traces are offset vertically for clarity. The arrows mark the magnetoplasmon resonance signal. The difference in SdH amplitudes between illumination on ($T \approx 1.7$ K) and off ($T \approx 1.5$ K) traces is due to a nonresonant heating of the 2DEG by the millimeterwave radiation.

$$\omega = j\omega_c$$

M. A. Zudov et al.
PRB, **64**, 201311(R) (2001)

Hall Field-Induced Resistance Oscillations

(HIRO, ω_H/ω_c - oscillations)

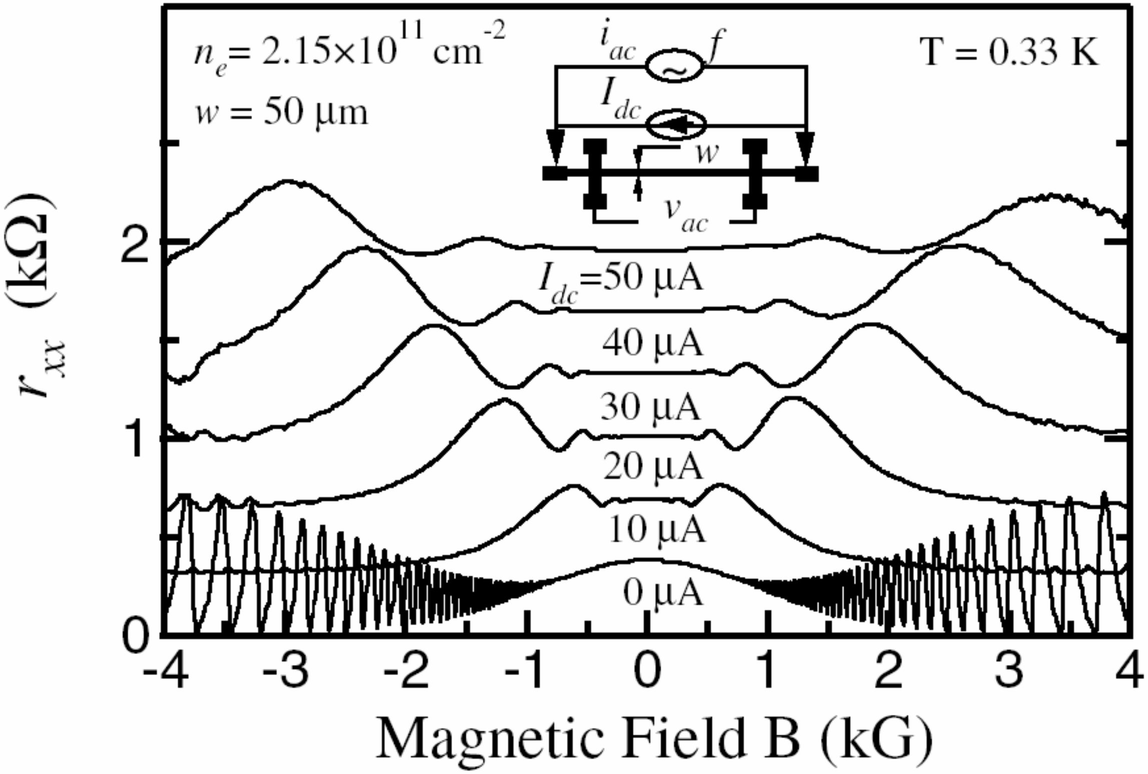
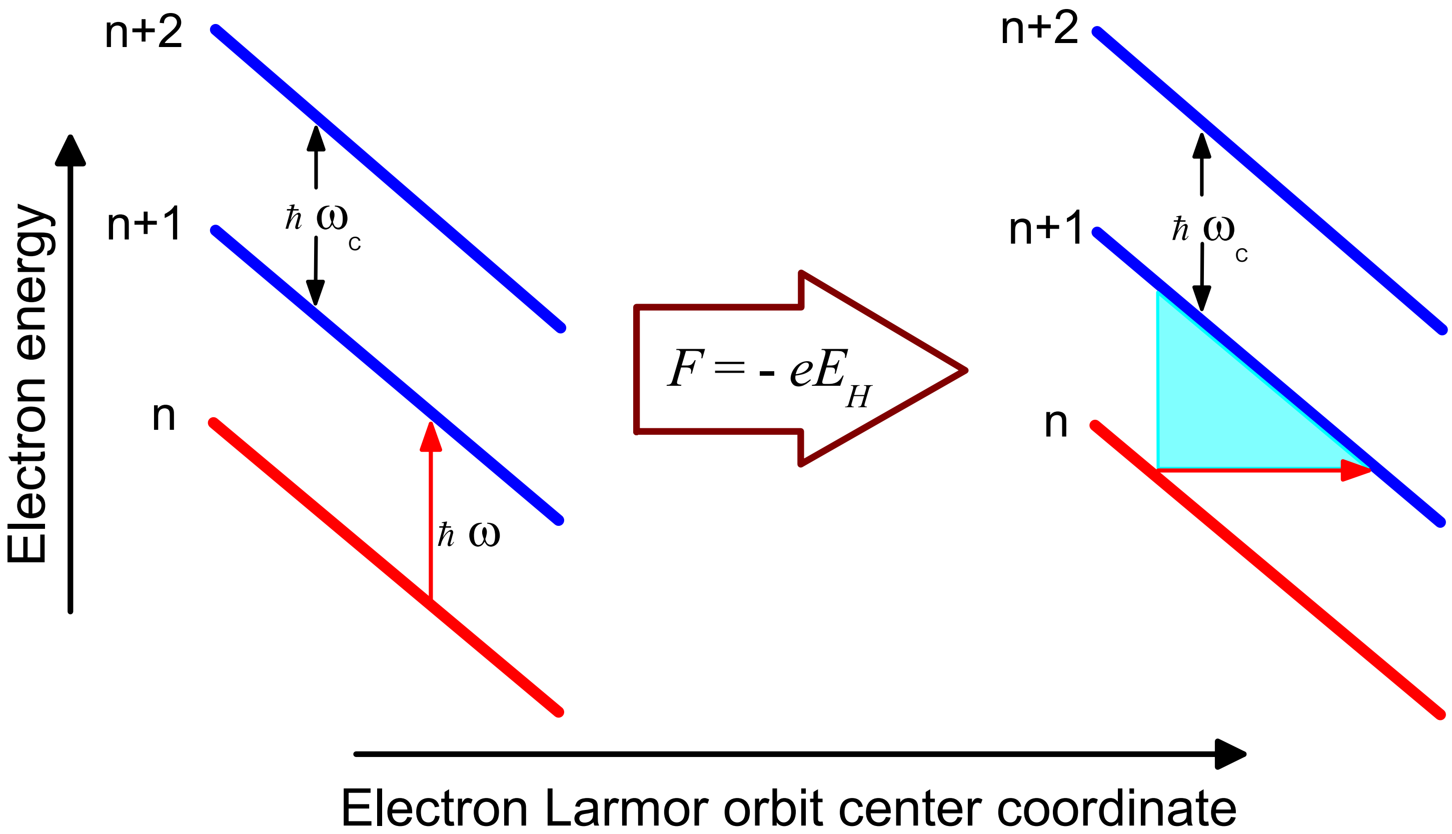


FIG. 1. The measured differential magnetoresistance traces at various dc current I_{dc} are shown for a 50 μm Hall bar (for clarity, the traces are shifted vertically in steps of 0.3 kΩ). Up to three orders of oscillations are clearly seen from the traces, and the oscillations are roughly periodic in $1/B$. The inset is a diagram for the electrical measurement.

$$2R_c eE_H = l\hbar\omega_c$$

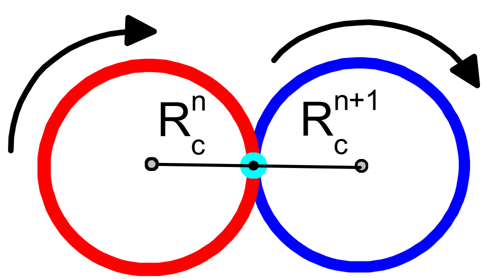
C. L. Yang et al.
PRL, **89**, 076801 (2002)

Electron-Impurity Scattering Induced by the Microwaves or DC bias



$$2k_F u_S = l\,\hbar\,\omega_c$$

$$\hbar\,\omega = l\,\hbar\,\omega_c$$

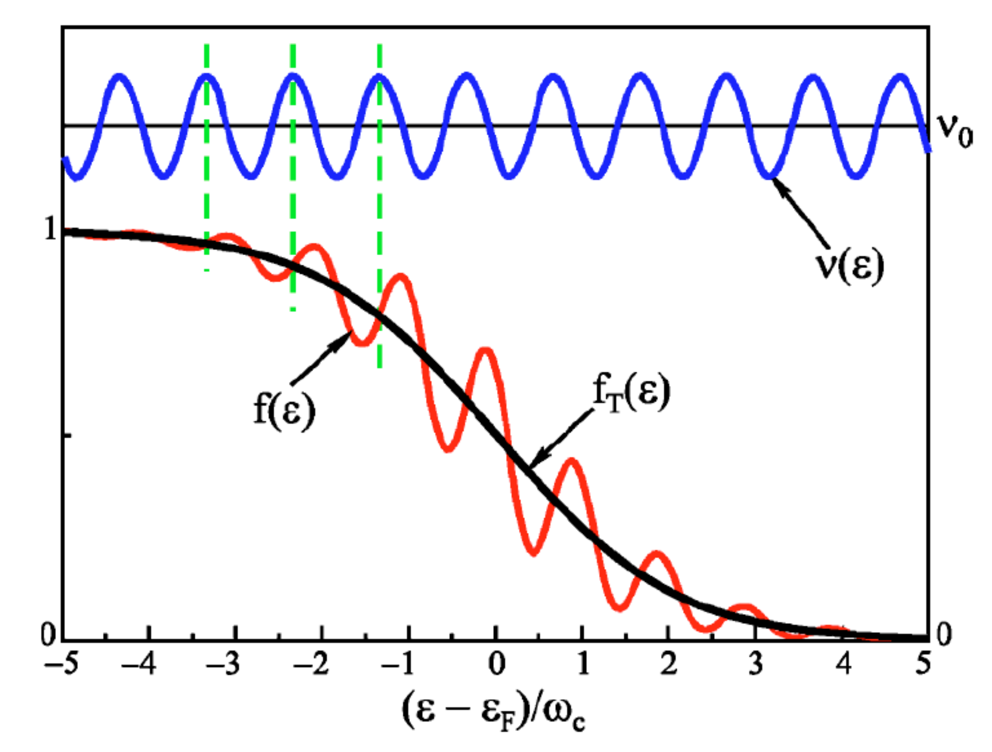


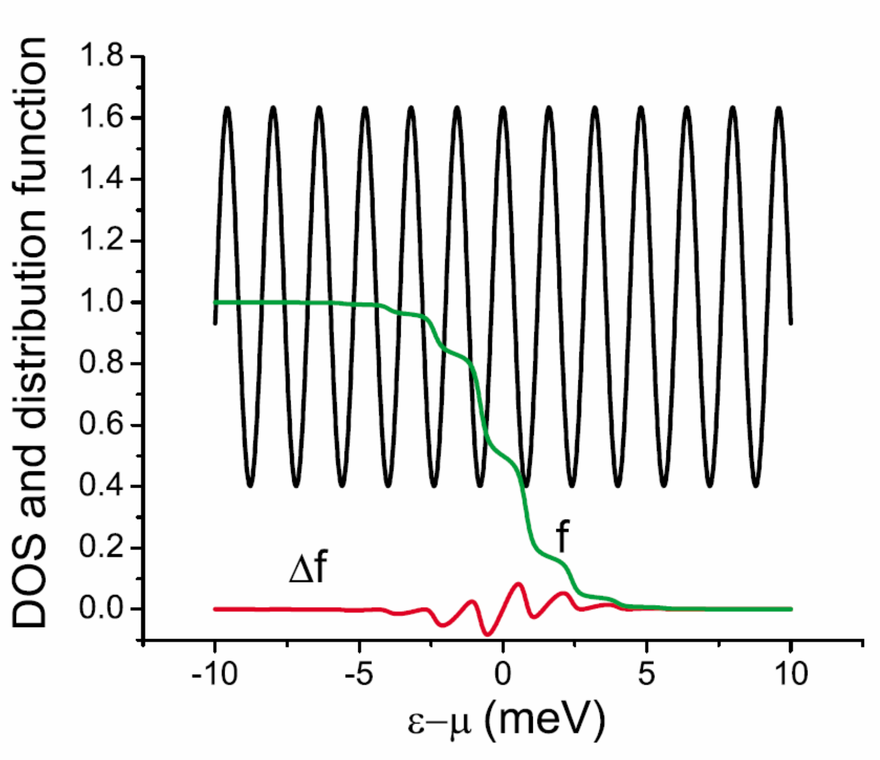
$$2R_c eE_H = l\,\hbar\,\omega_c$$

Electron Distribution in the Energy space

$$\sigma_{\rm ph} = \int d\varepsilon\,\sigma_{\rm dc}(\varepsilon)[-\partial_\varepsilon f(\varepsilon)]$$

$$\tilde{\nu} = 1 - 2\delta\cos\frac{2\pi\varepsilon}{\omega_c}, \qquad \delta = \exp\left(-\frac{\pi}{\omega_c\tau_q}\right) \ll 1$$



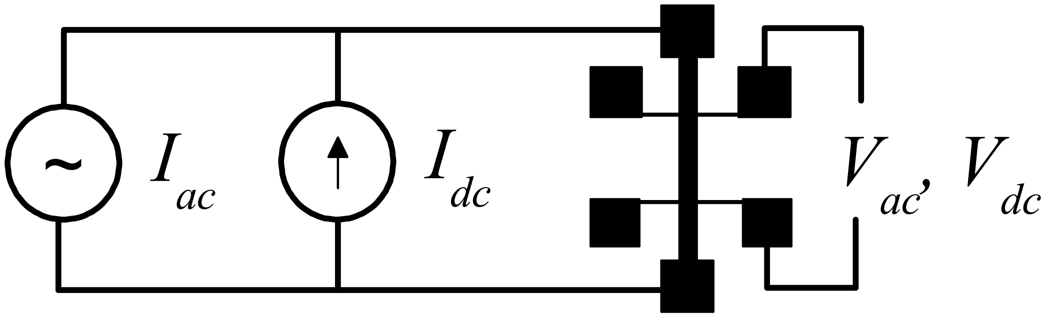


I. A. Dmitriev et al. PRB, **71**, 115316 (2005).

2. Experiment

Samples were **GaAs quantum wells** grown by solid source molecular beam epitaxy on semi-insulating (001) GaAs substrates. Density and mobility of the 2D electrons were:

n_e= (0.7 - 1.2) 10^{12} cm^{-2} and μ = (0.5 – 2) 10^6 cm^2/Vs.



$F = 1 - 140$ GHz

$V_{dc}(I_{dc})$

$V_{dc}/I_{dc} = R_0$

$V_{ac}/I_{ac} = r_{xx}$

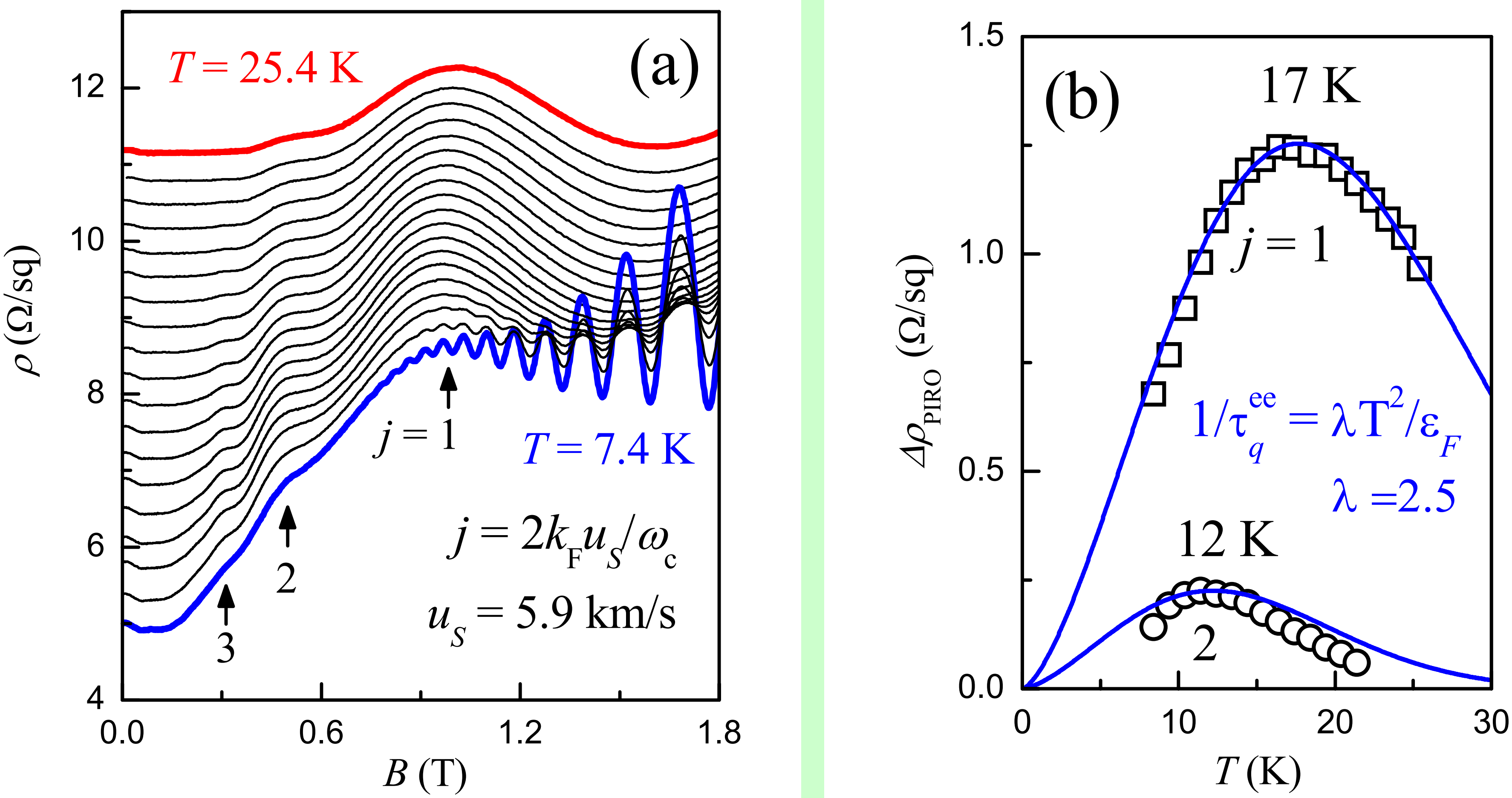
$V_{ac}^{(0)}, V_{ac}^{(1)}$

$V_{ac}^{(2)}, V_{ac}^{(3)}$

$$V = R_0 I_{dc} + V^{(0)} + V^{(1)} + V^{(2)} + V^{(3)} + \dots$$

3. Results

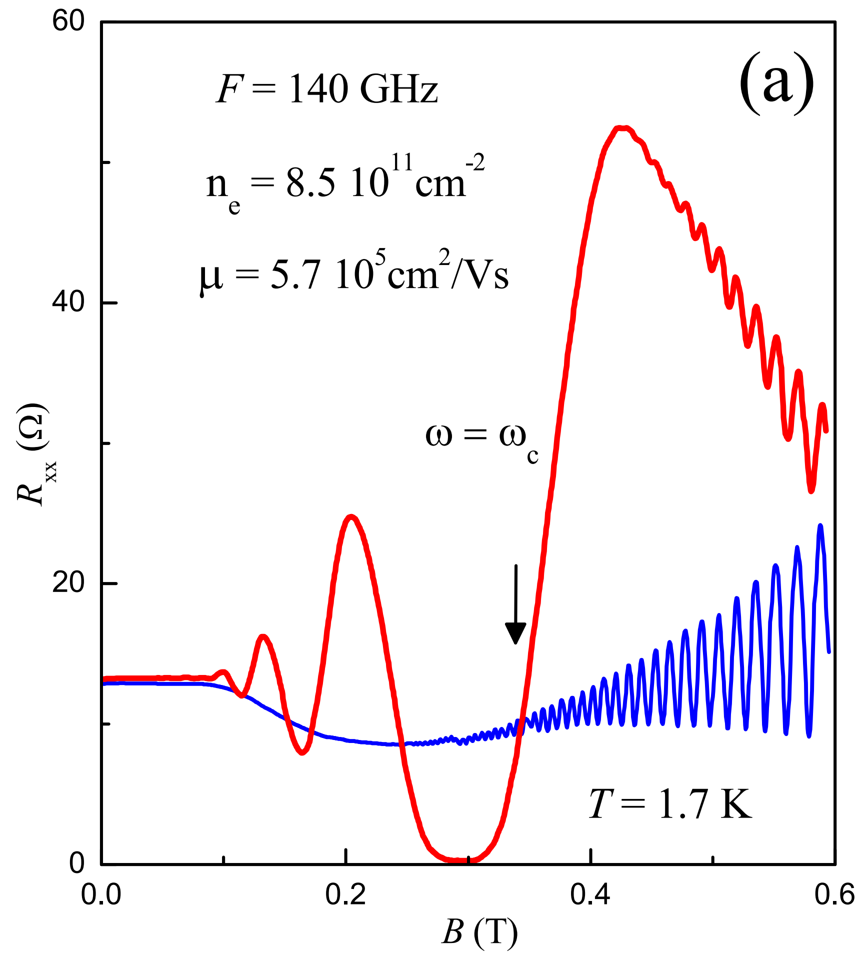
Phonon-Induced Resistance Oscillations

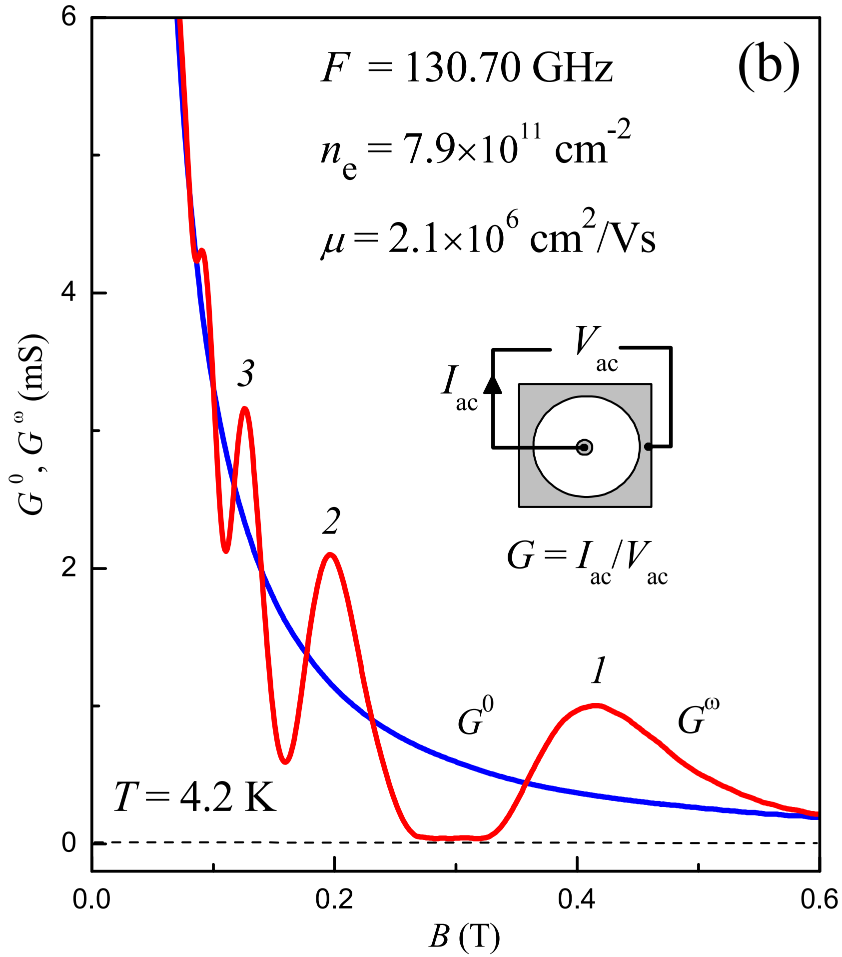


A. A. Bykov et al. JETP Letters, **81**, 553 (2005), JETP Letters, **90**, 578 (2009).

Theory: O. E. Raichev. PRB, **80**, 075318 (2009).

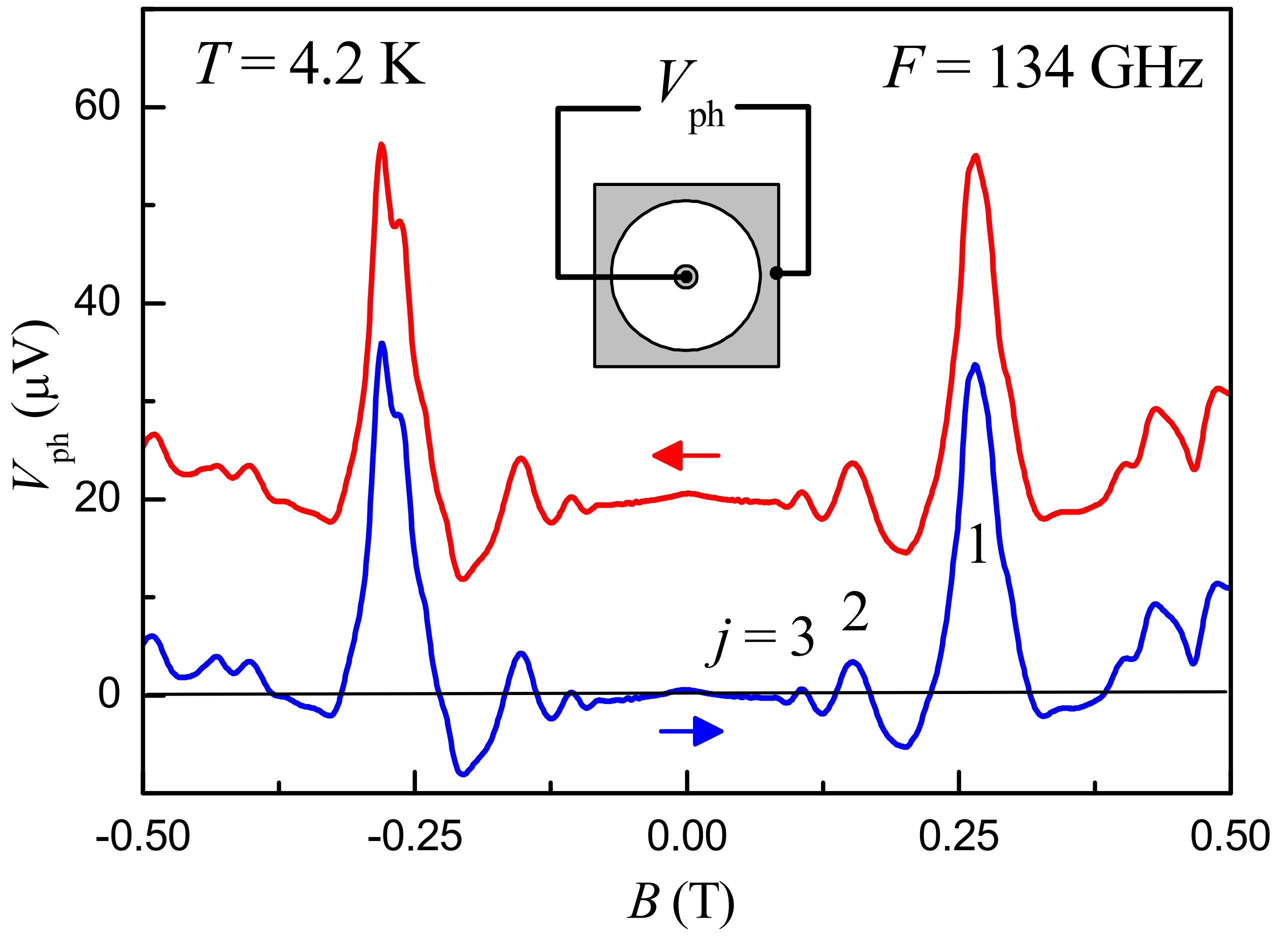
Microwave-Induced Resistance and Conductance Oscillations





A. A. Bykov et al. JETP Letters, **84**, 391 (2006), JETP Letters, **87**, 551 (2008).

Microwave-Induced Photovoltage Oscillations

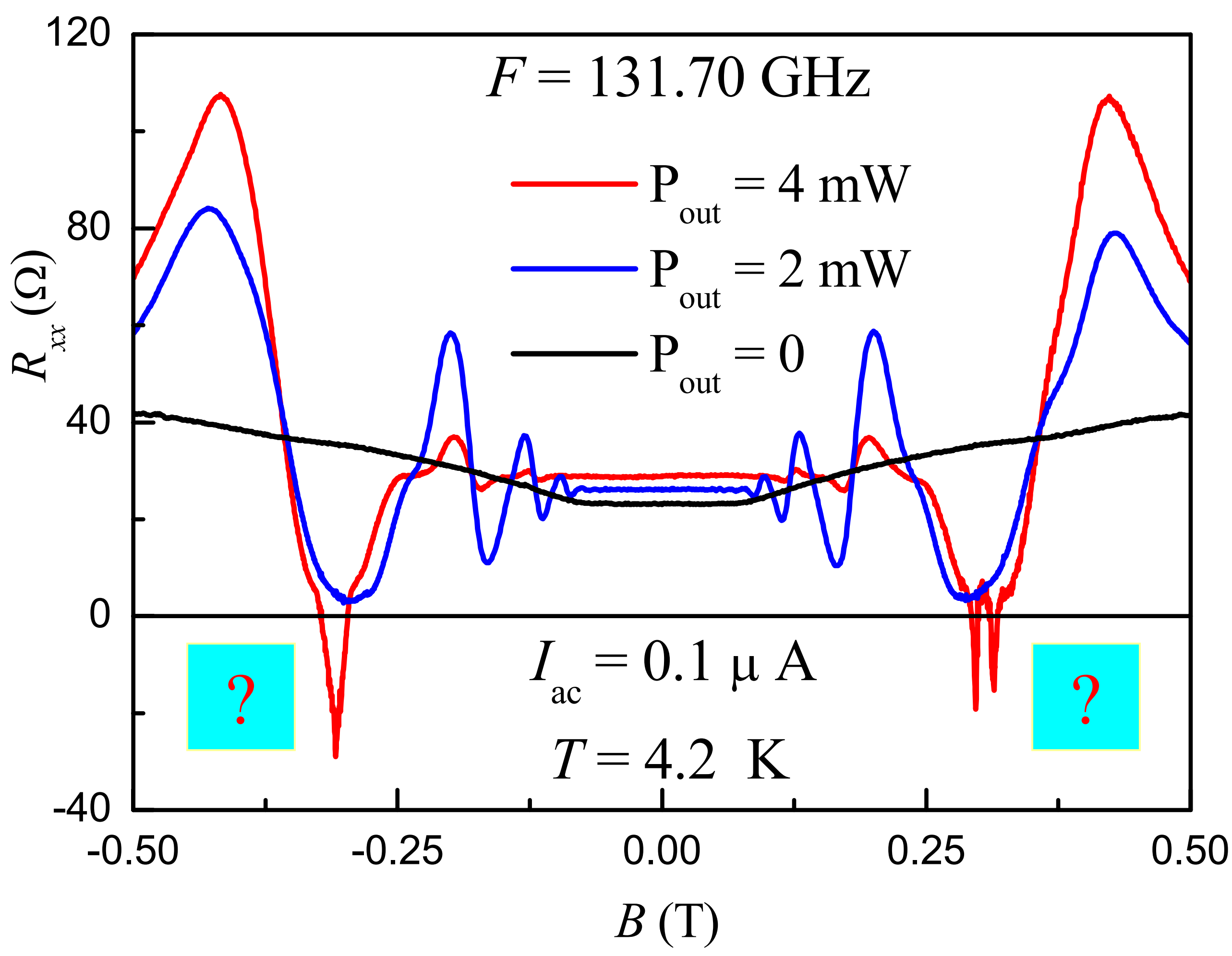


R. L. Willet et al.
PRL, **93**, 026804 (2004).

A. A. Bykov.
JETP Letters, **87**, 233 (2008).

S. I. Dorozhkin et al.
PRL, **102**, 036602 (2009).

Microwave-Induced Absolute Negative Resistance in a 2D Electron System

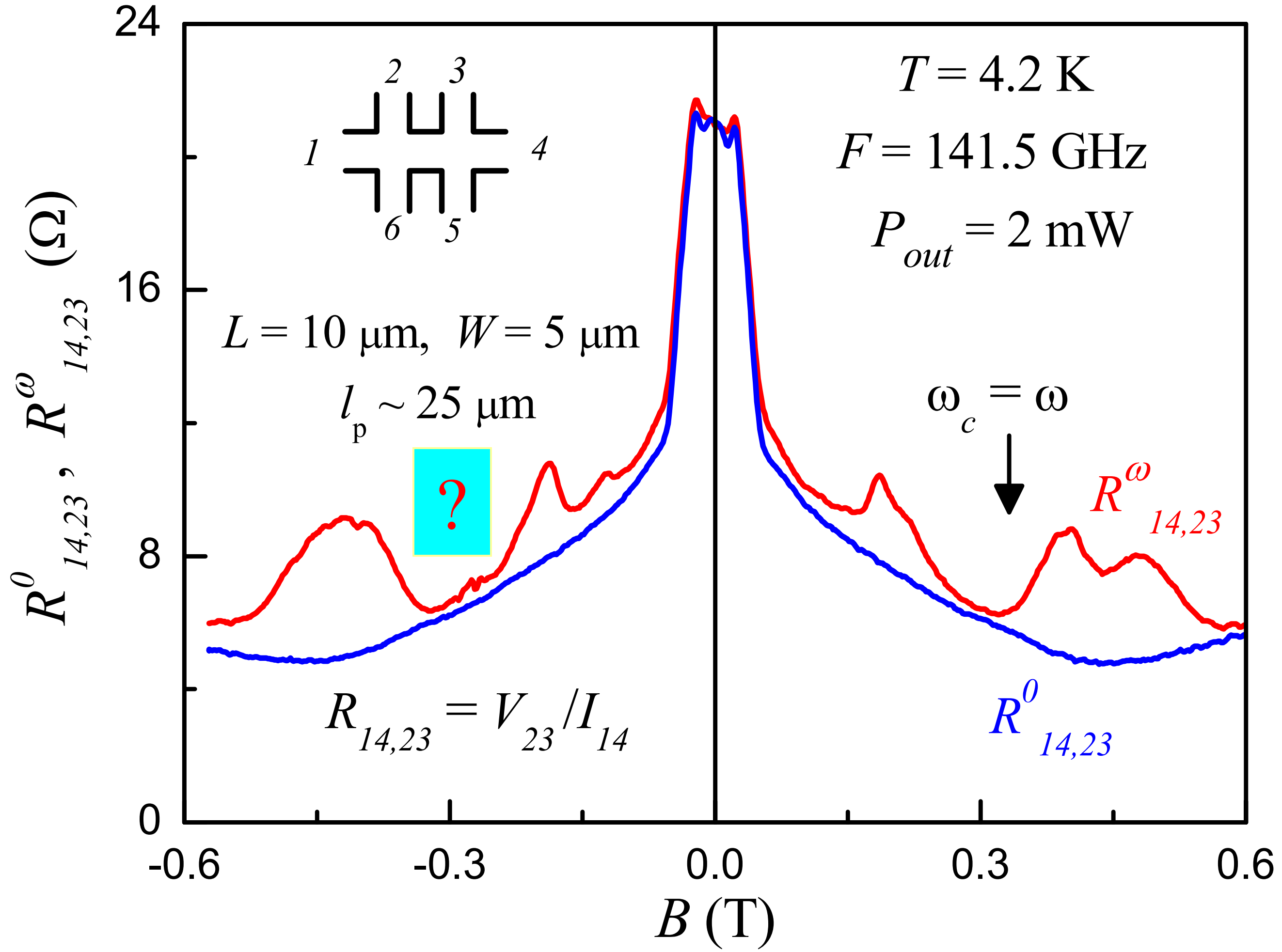


R. L. Willet et al.
PRL, **93**, 026804 (2004).

M. A. Zudov et al.
PRB, **73**, 041303 (2006).

A. A. Bykov et al. JETP Letters, **86**, 608 (2007).

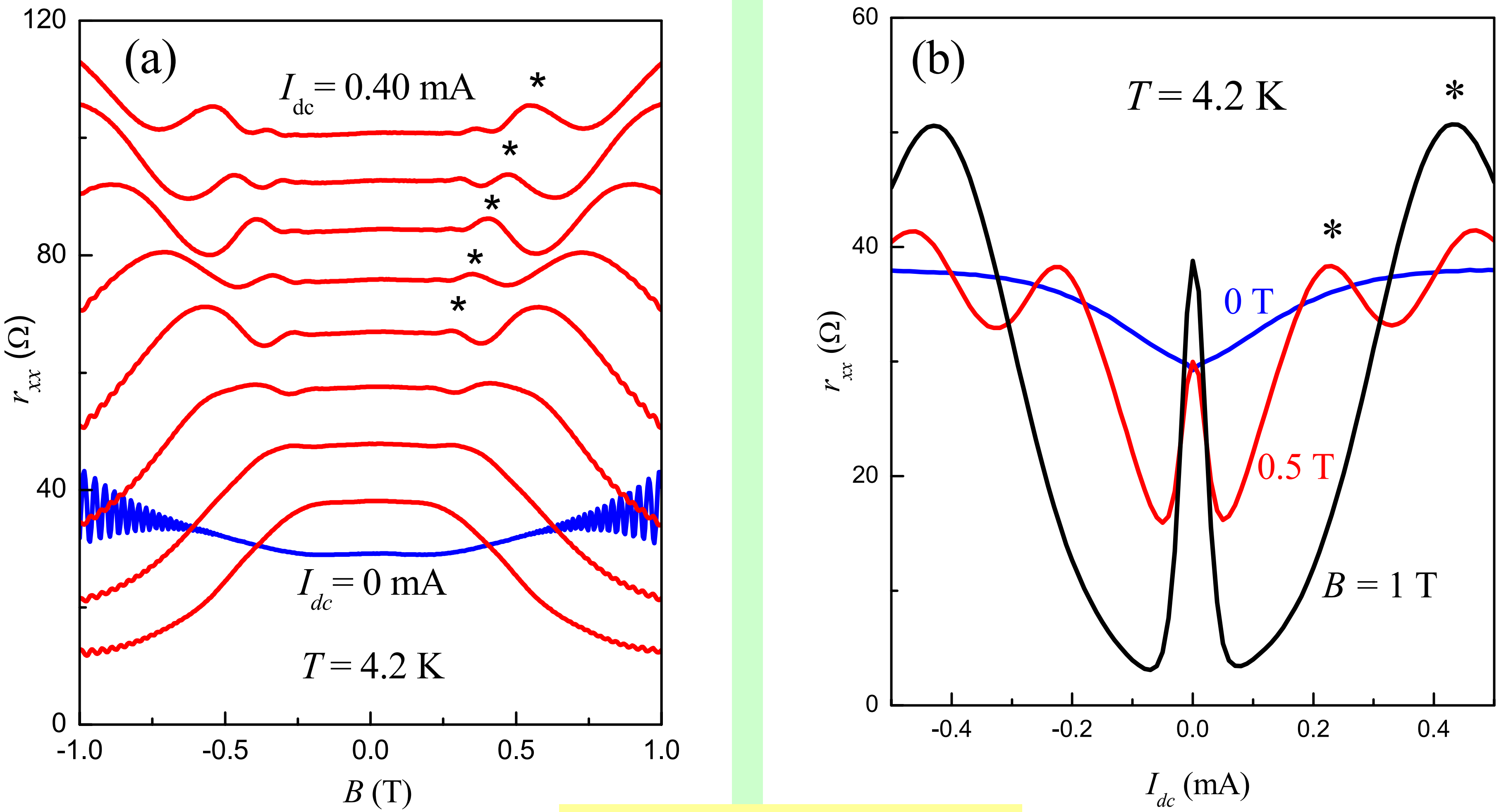
Microwave-Induced Resistance Oscillations in a Ballistic Microbar



Theory:
A. D. Chepelianskii, D. L. Shepelyansky
PRB, **80**, 241308 (R) (2009).

A. A. Bykov. JETP Letters, **89**, 575 (2009).

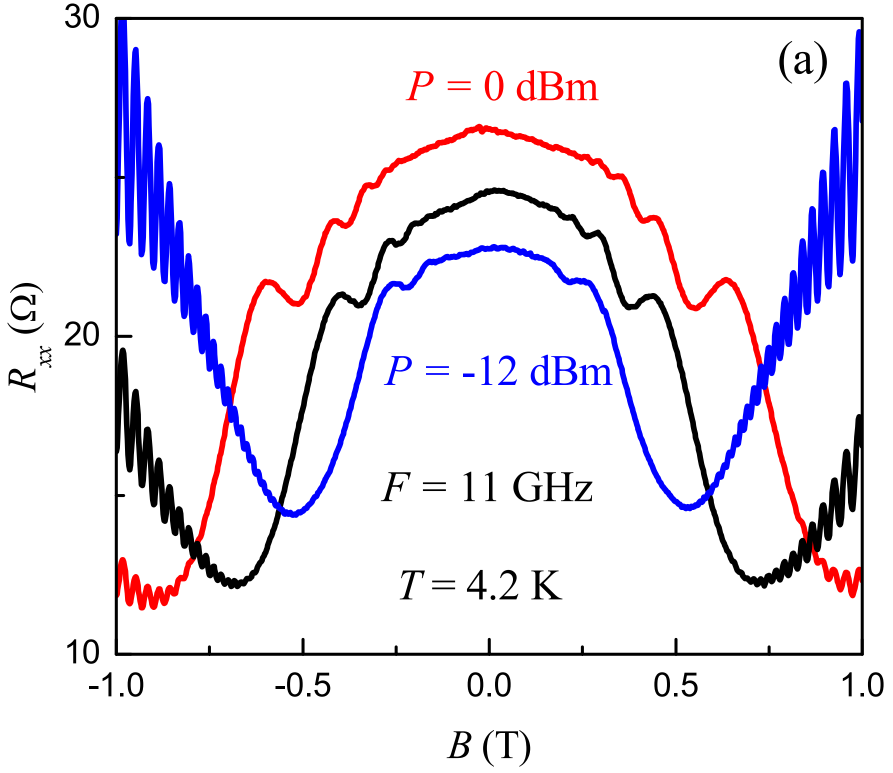
Hall Field-Induced Resistance Oscillations

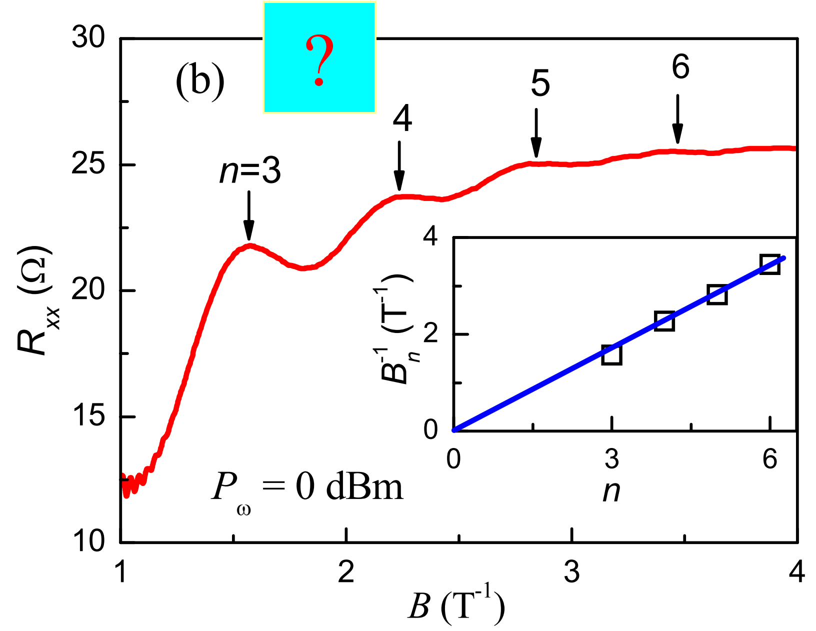


$$2R_c eE_H = l\hbar\omega_c$$

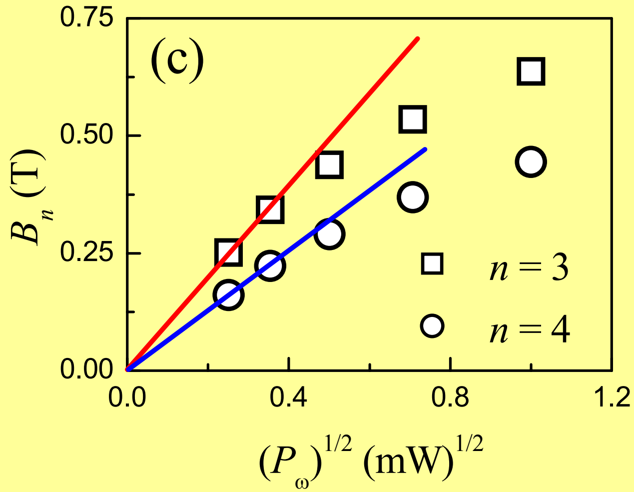
A. A. Bykov et al. JETP Letters, **81**, 284 (2005), PRB, **72**, 245307 (2005).

AC excitation 11 GHz



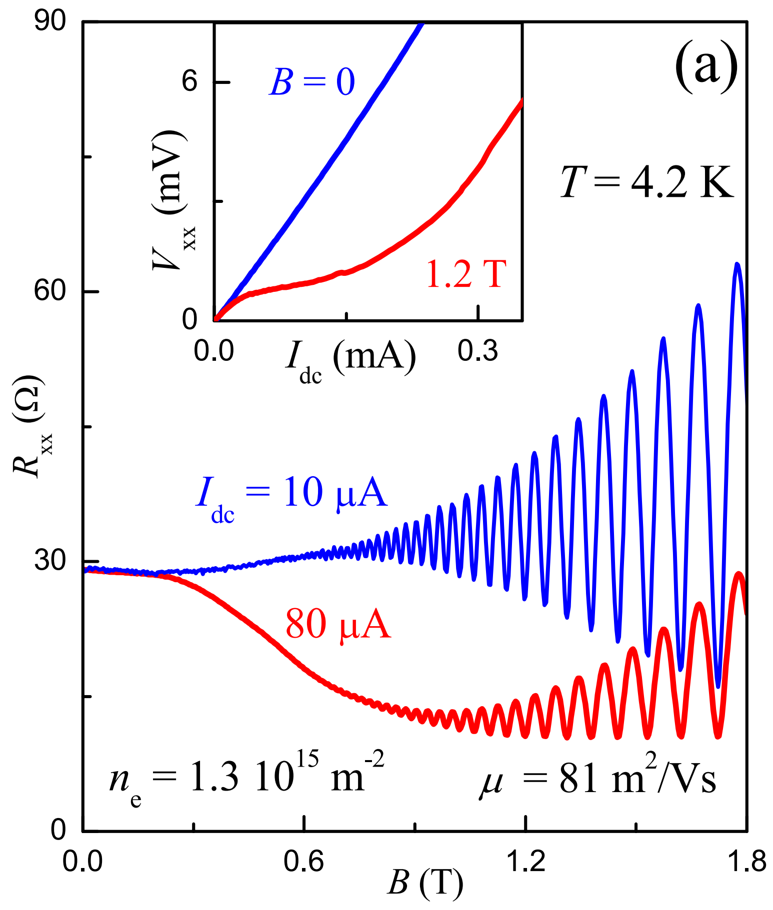


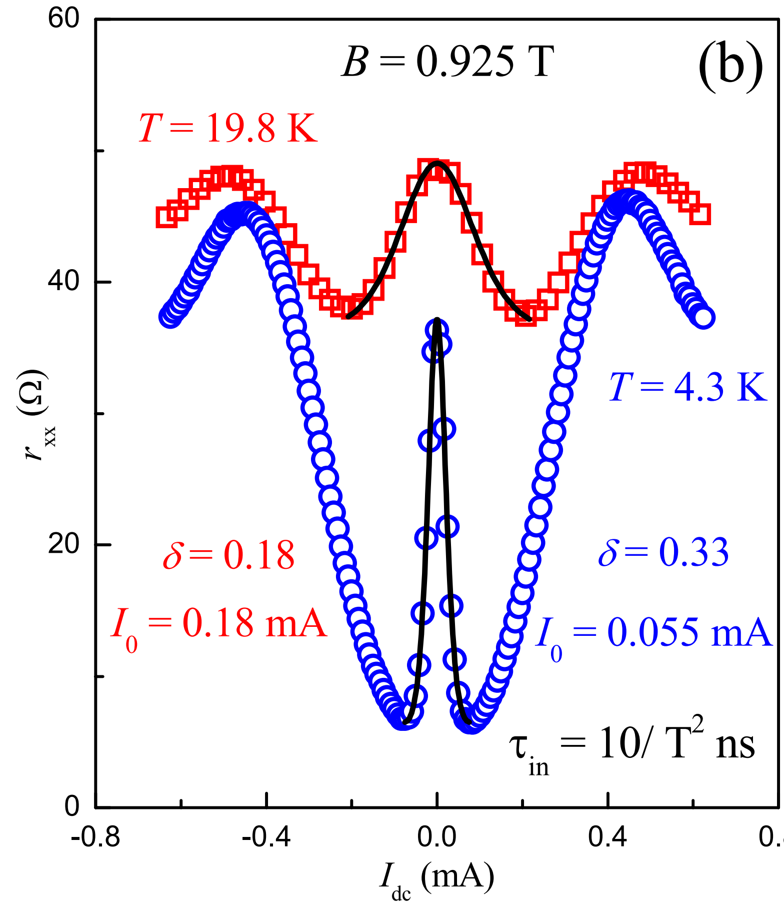
For a linear microwave circuit current density through the sample should be proportional to square root of the input microwave power $J_\omega \sim (P_\omega)^{1/2}$.



A. A. Bykov et al. PRB, **72**, 245307 (2005).

Effect of a DC Electric Field on the Longitudinal Resistance



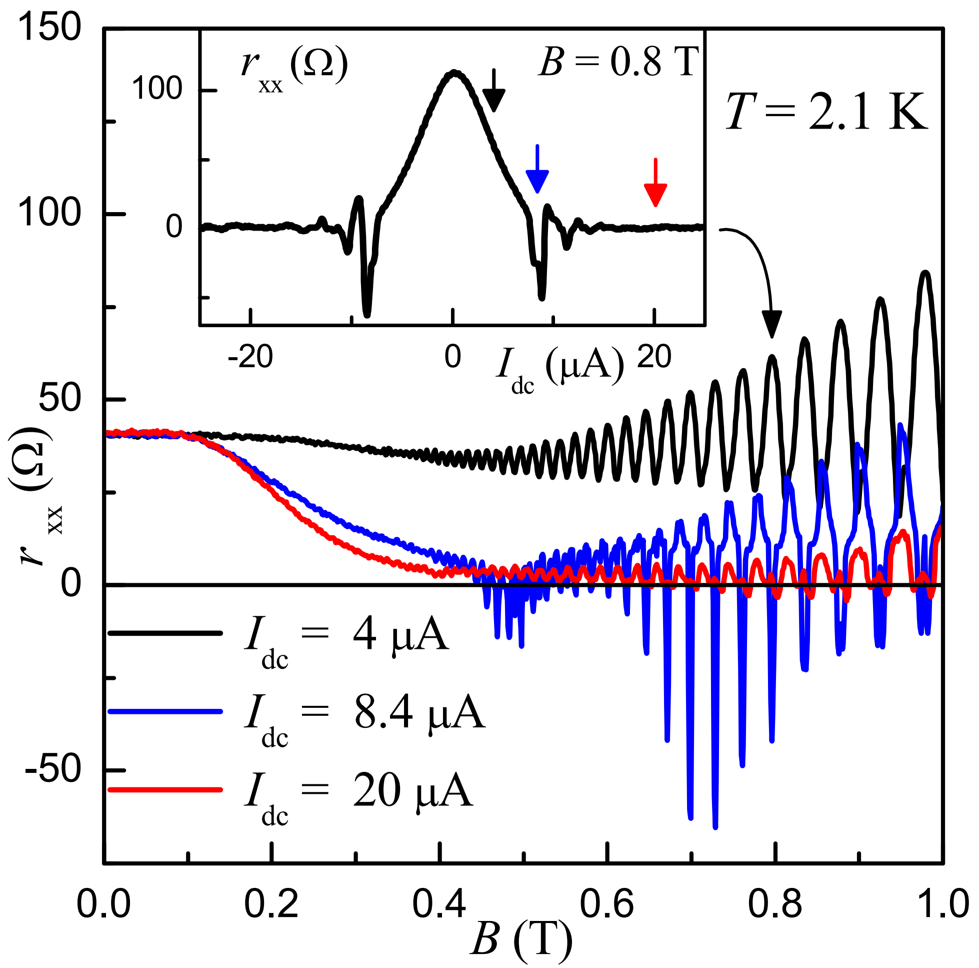


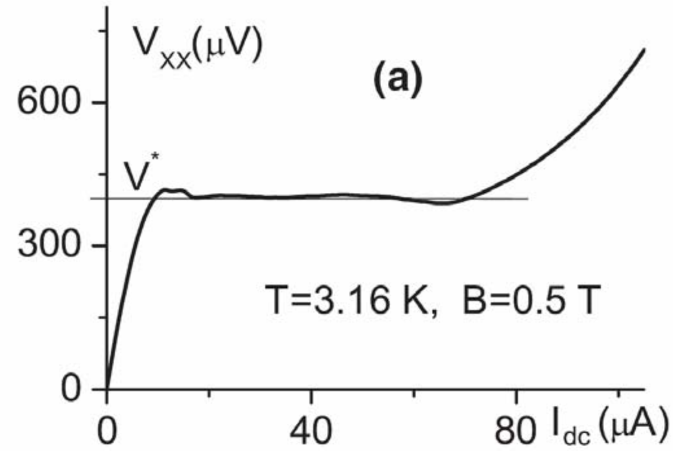
J. Q. Zhang et al. PRB, **75**, 081305 (2007).

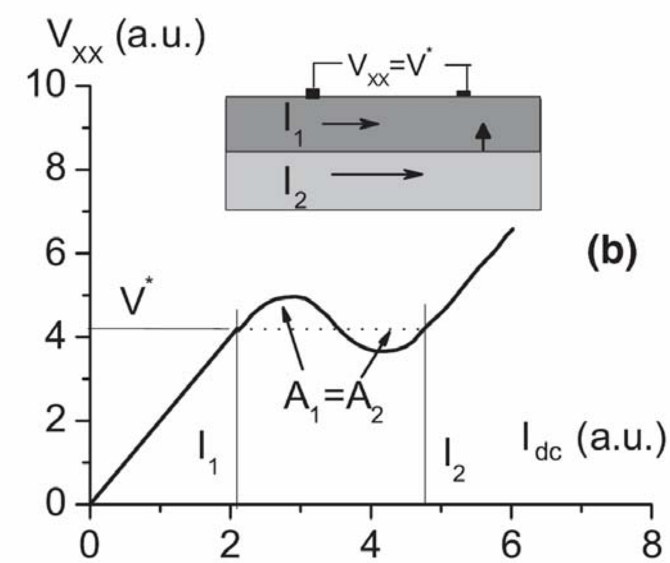
A. A. Bykov et al.
JETP Letters, **81**, 406 (2005).

Theory: I. A. Dmitriev et al.
PRB, **71**, 115316 (2005).

Zero-Differential Resistance State



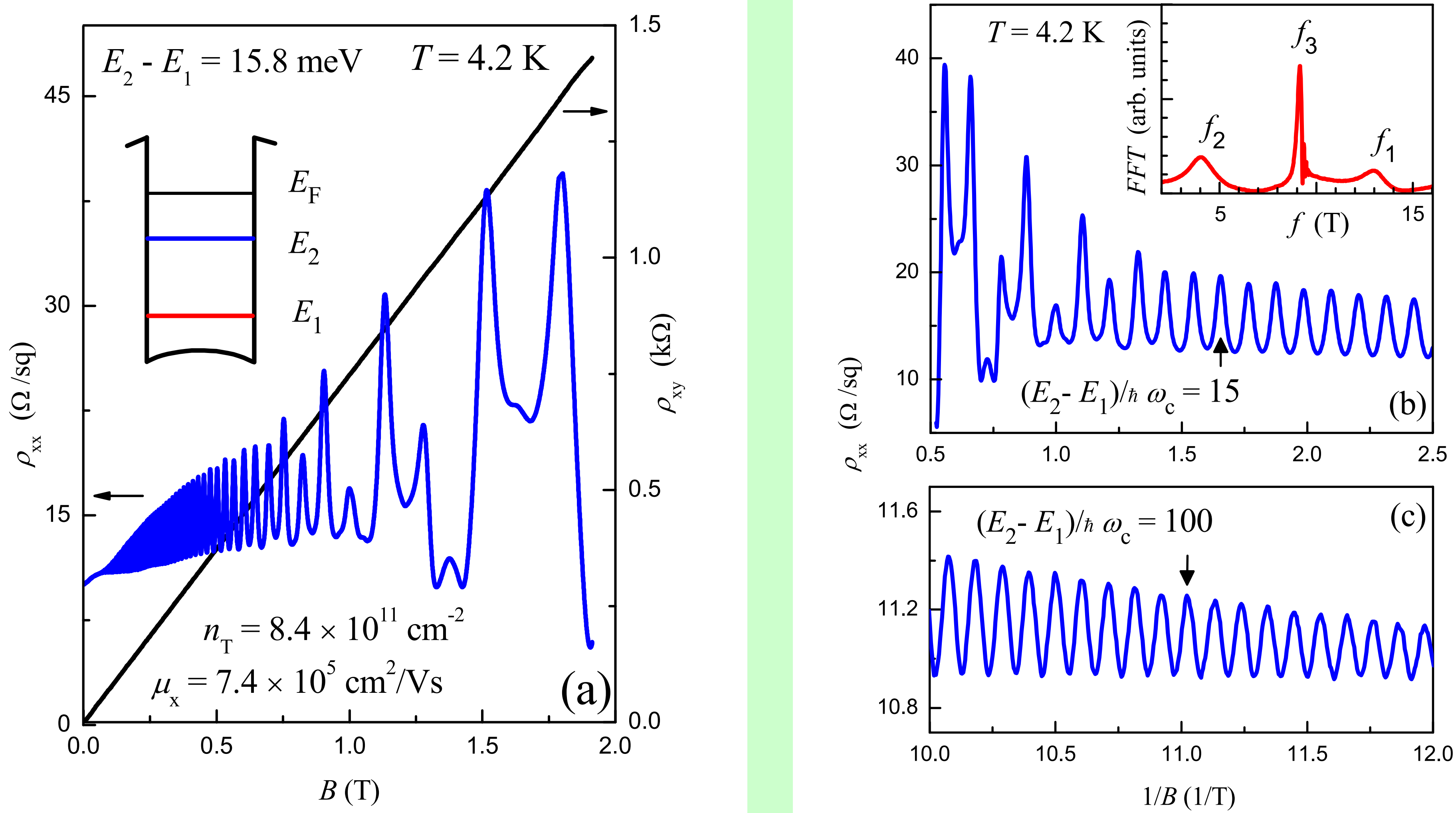




N. Romero Kalmanovitz et al.
PRB, **78**, 085306 (2008).

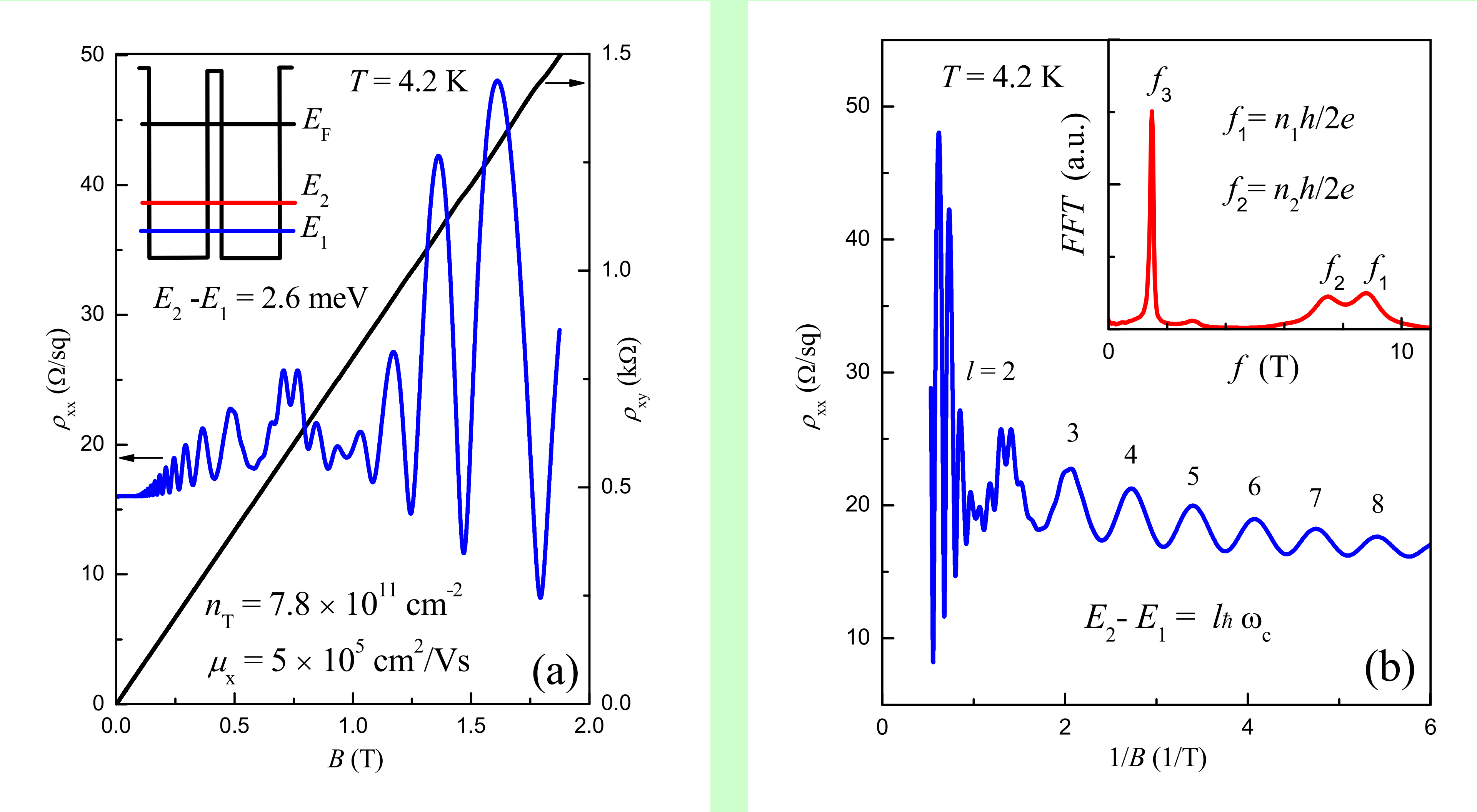
A. A. Bykov et al.
PRL, **99**, 116801 (2007).

Single Quantum Well With Two Populated Subbands



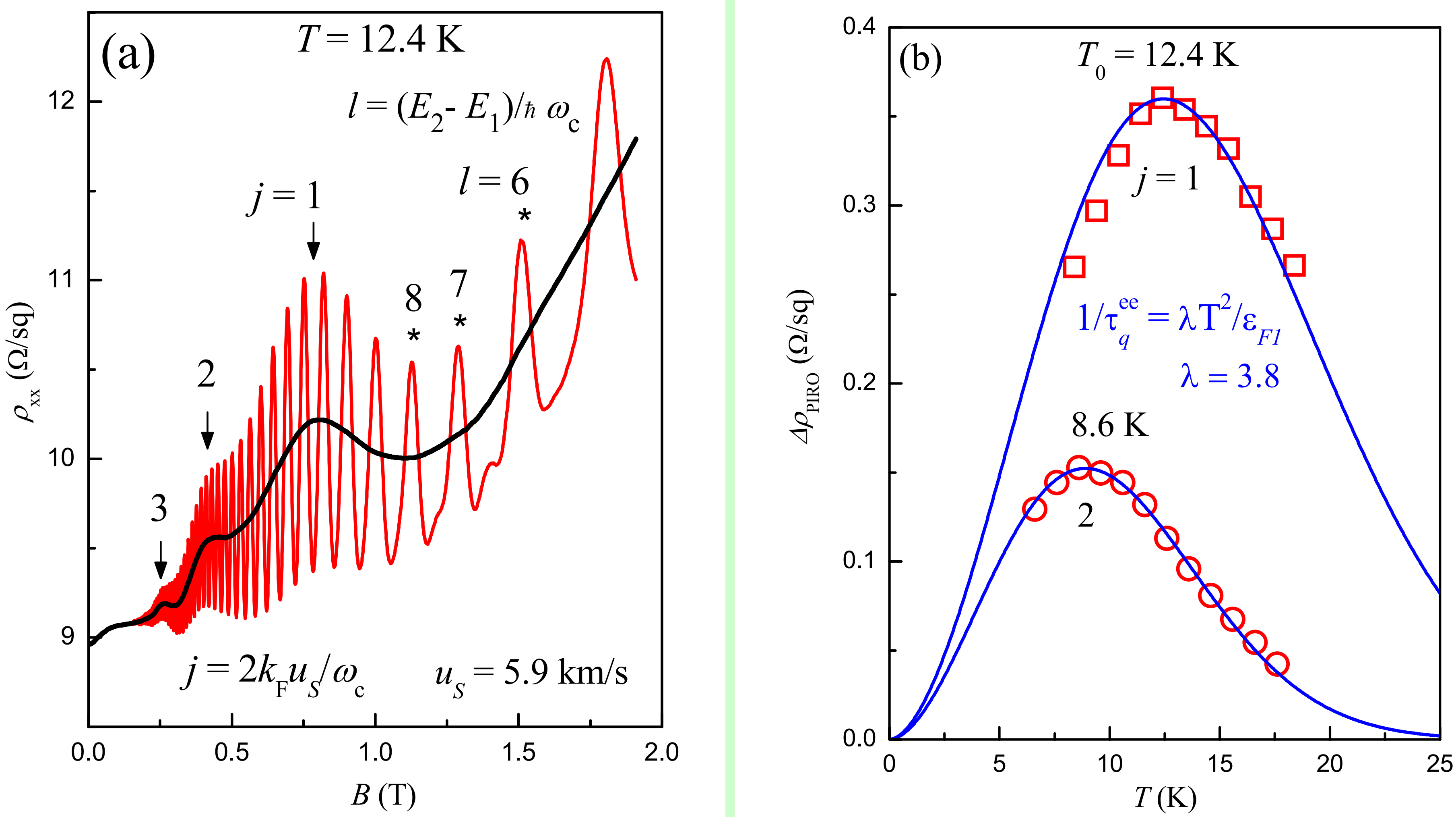
A. V. Goran et al. PRB, **80**, 193305 (2009).

Duble Quantum Well With Two Populated Subbands



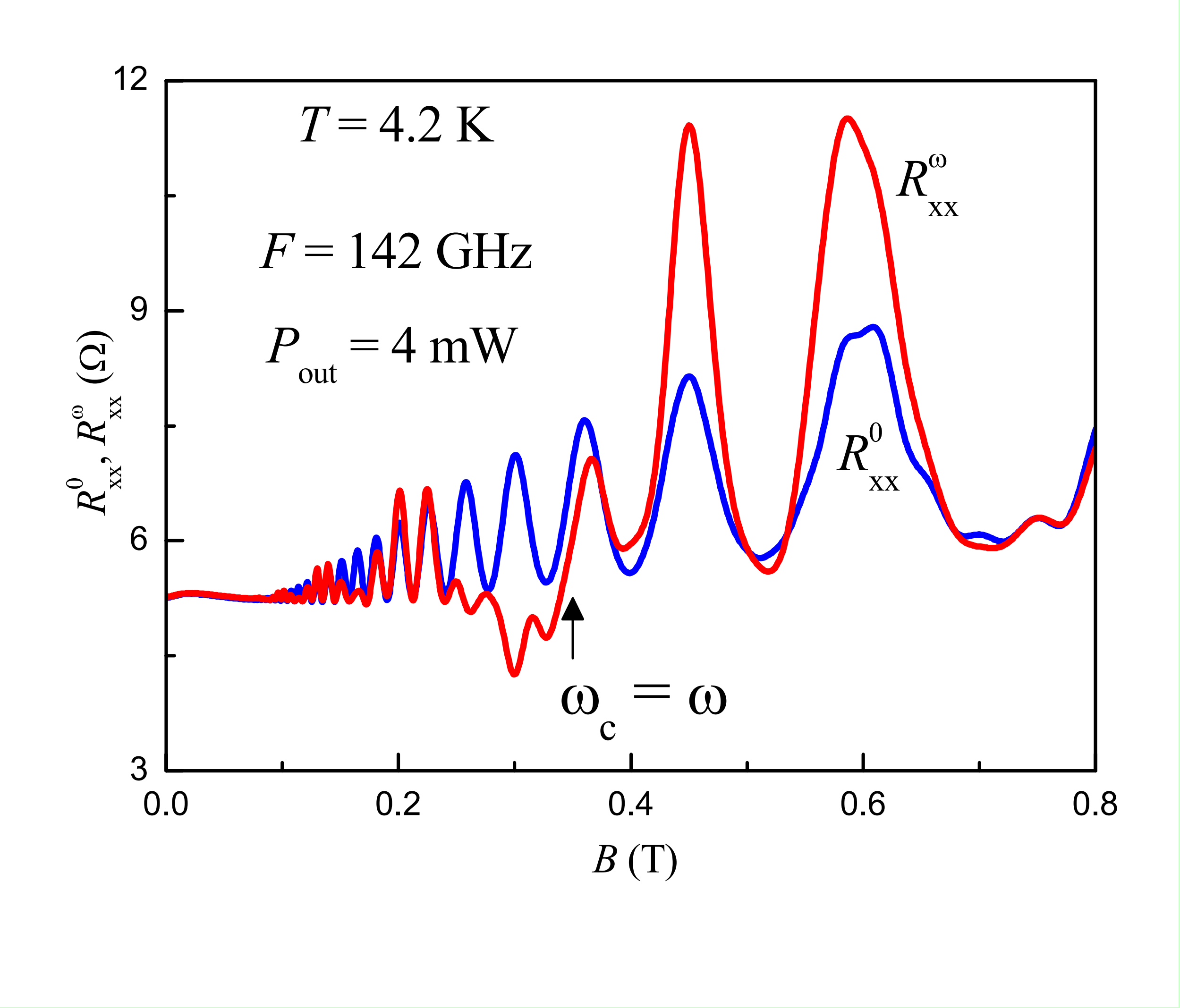
A. A. Bykov et al. JETP Letters, **88**, 64 (2008).

Phonon-Induced Resistance Oscillations in single quantum wells with two populated subbands



A. A. Bykov et al. cond-mat / arXiv : 0912.4366 (2009).

Microwave-Induced Resistance Oscillations in Double Quantum Wells



A. A. Bykov et al. JETP Letters, **87**, 477 (2008).

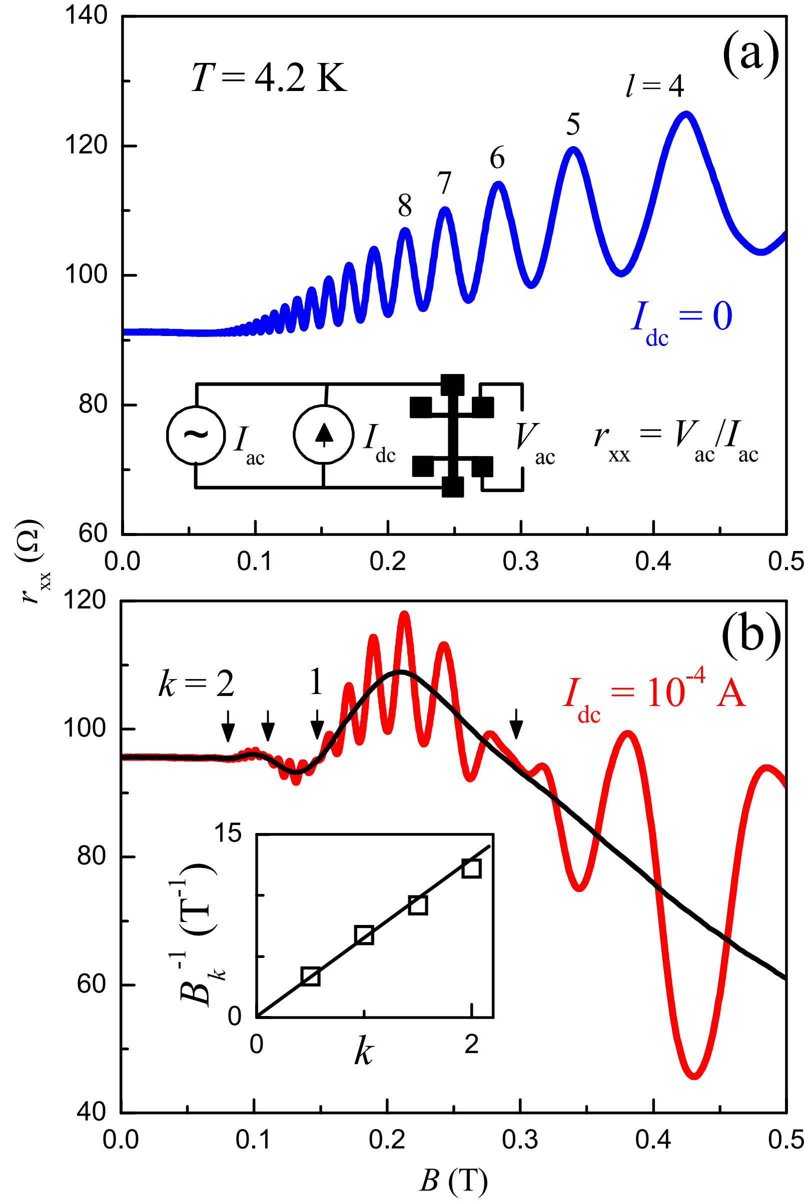
S.Wiedman, G.Gusev, O.Raichev et al. PRB, **78**, 121301(R) (2008).

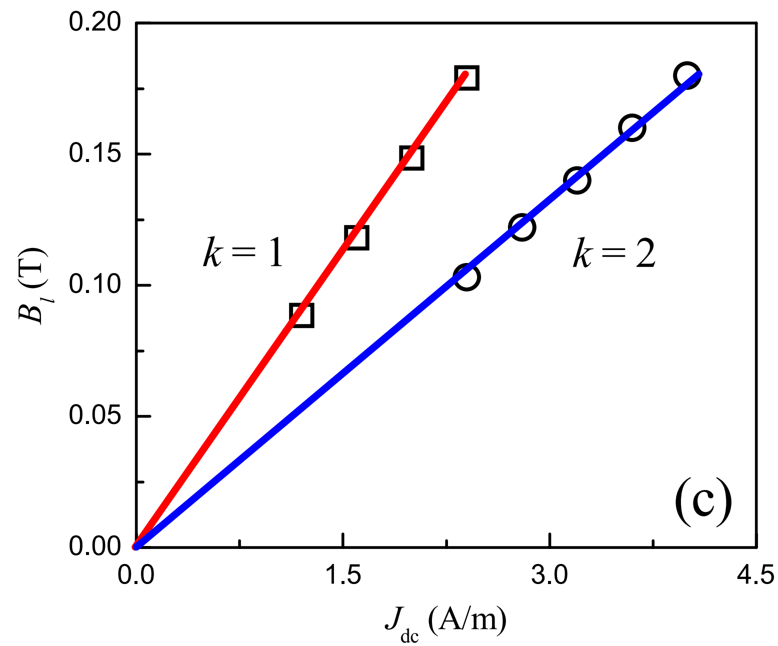
Туннелирование Зинера в двойной квантовой яме

$$\omega_H/\omega_c = k$$

$$\omega_H = e\gamma R_c E_H \hbar$$

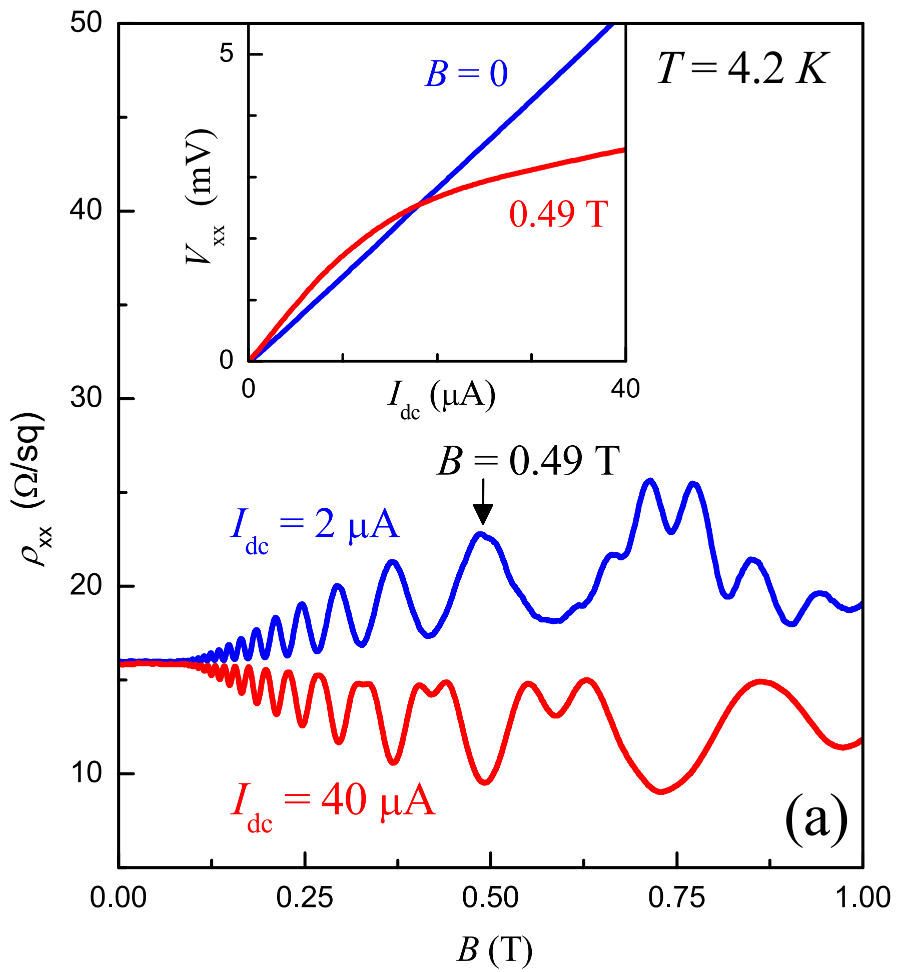
$$\omega_H \sim \gamma e^{-1}(\pi/n_T)^{1/2} J_{dc}$$

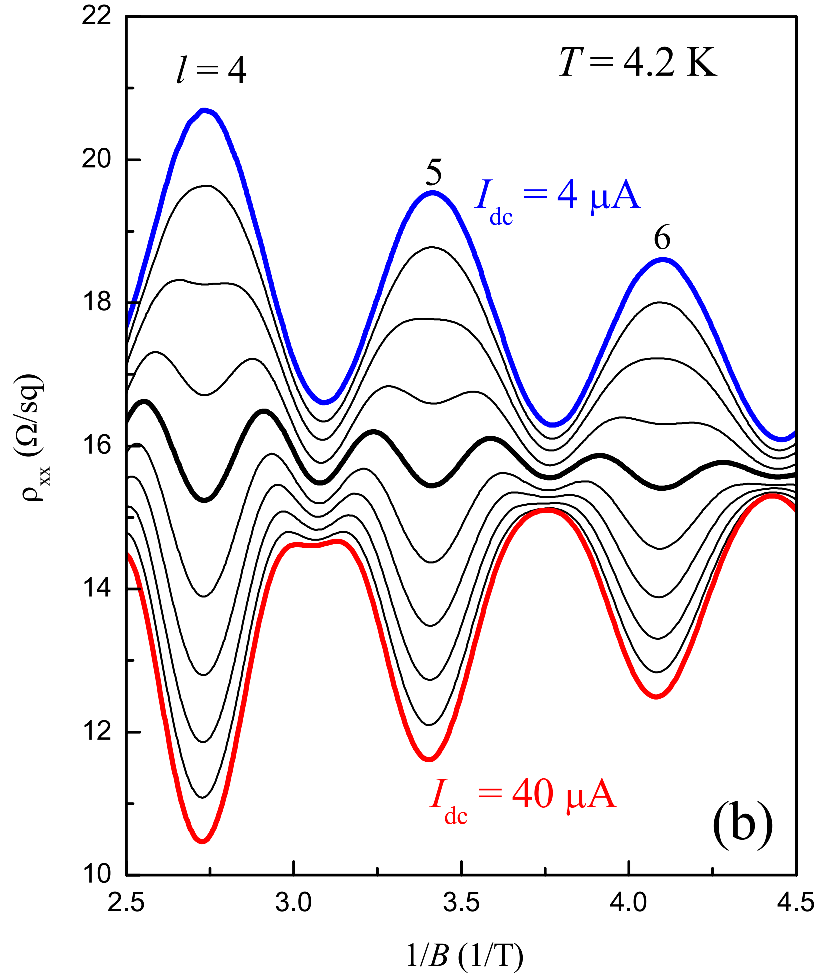




A. A. Bykov. JETP Letters, **88**, 394 (2008).

Инверсия магнето-межподзонных осцилляций

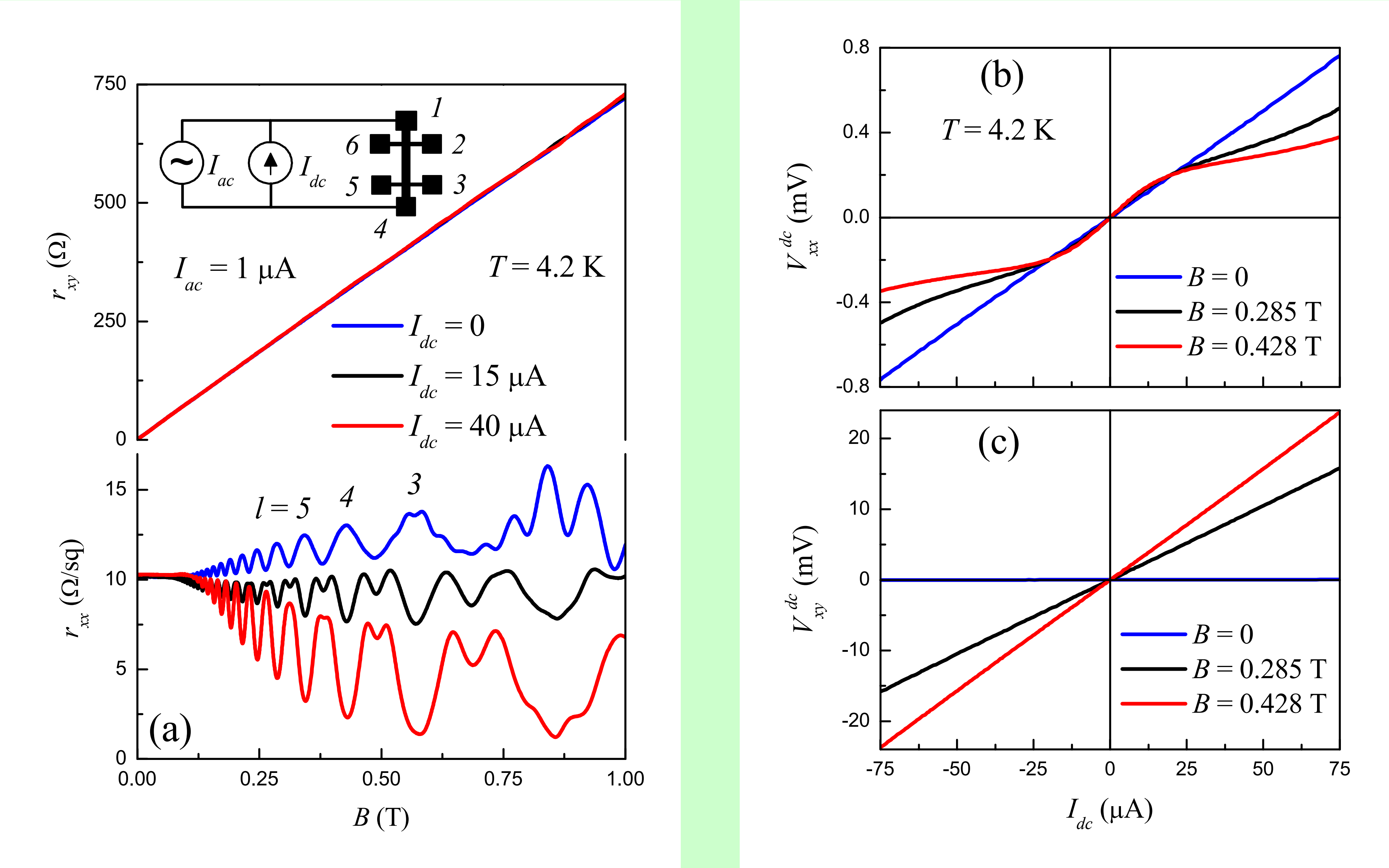




A. A. Bykov. JETP Letters, **88**, 64 (2008).

N.Mamani, G.Gusev, O.Raichev et al. PRB, **80**, 075308 (2009).

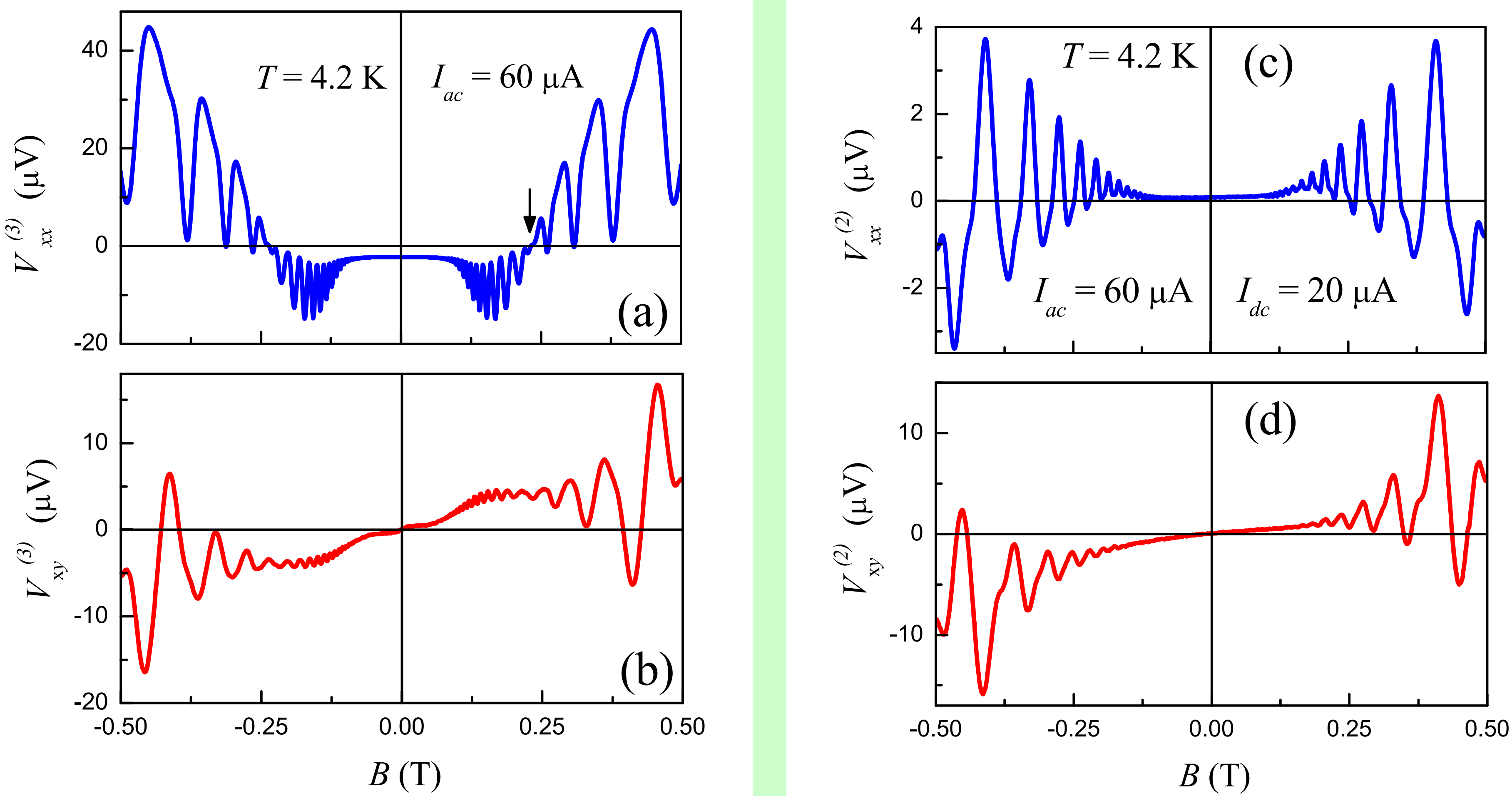
Дифференциальное сопротивление и ВАХ



A. A. Bykov. JETP Letters, **89**, 461 (2009).

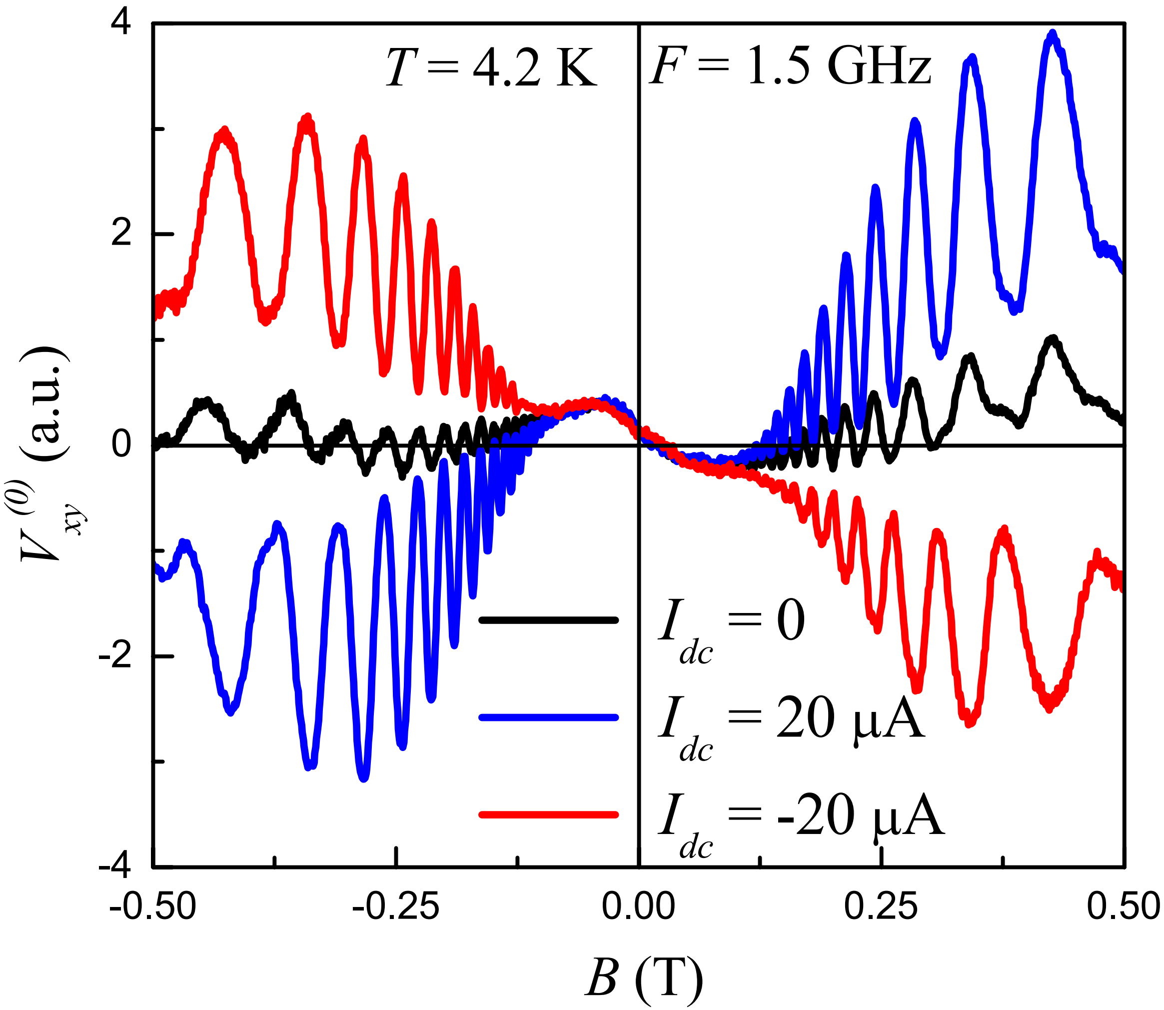
Генерация гармоник в двойной квантовой яме

$$V = R_0 I_{dc} + V^{(0)} + V^{(1)} + V^{(2)} + V^{(3)} + \ldots$$



A. A. Bykov. JETP Letters, **89**, 461 (2009).

ЭДС Холла в двойной квантовой яме



A. A. Bykov. JETP Letters, **89**, 461 (2009).

4. Conclusion