Spontaneous current oscillation in 2D electrons on liquid helium

induced by intersubband excitation under magnetic fields

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Thanks

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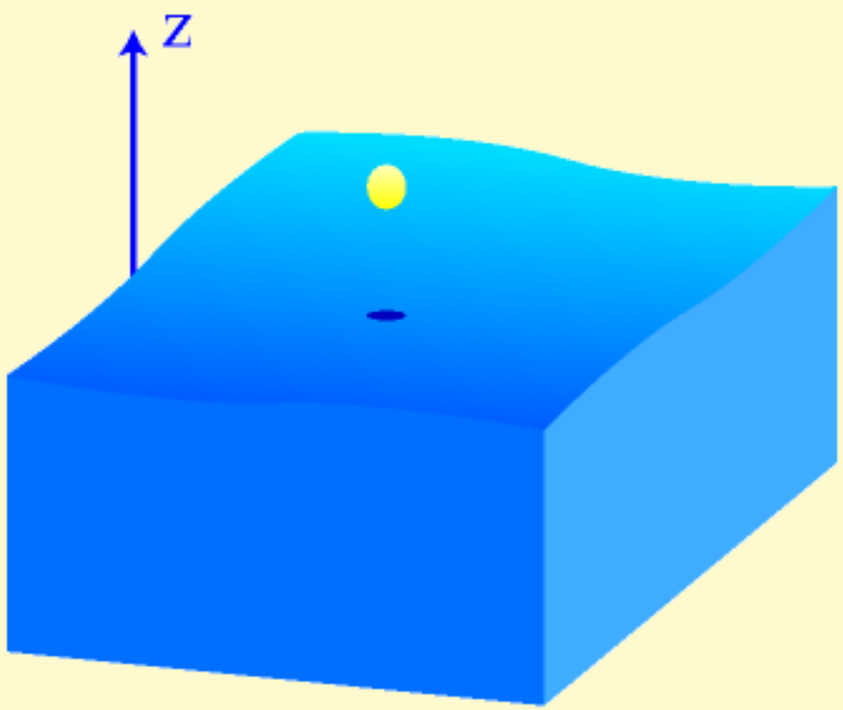
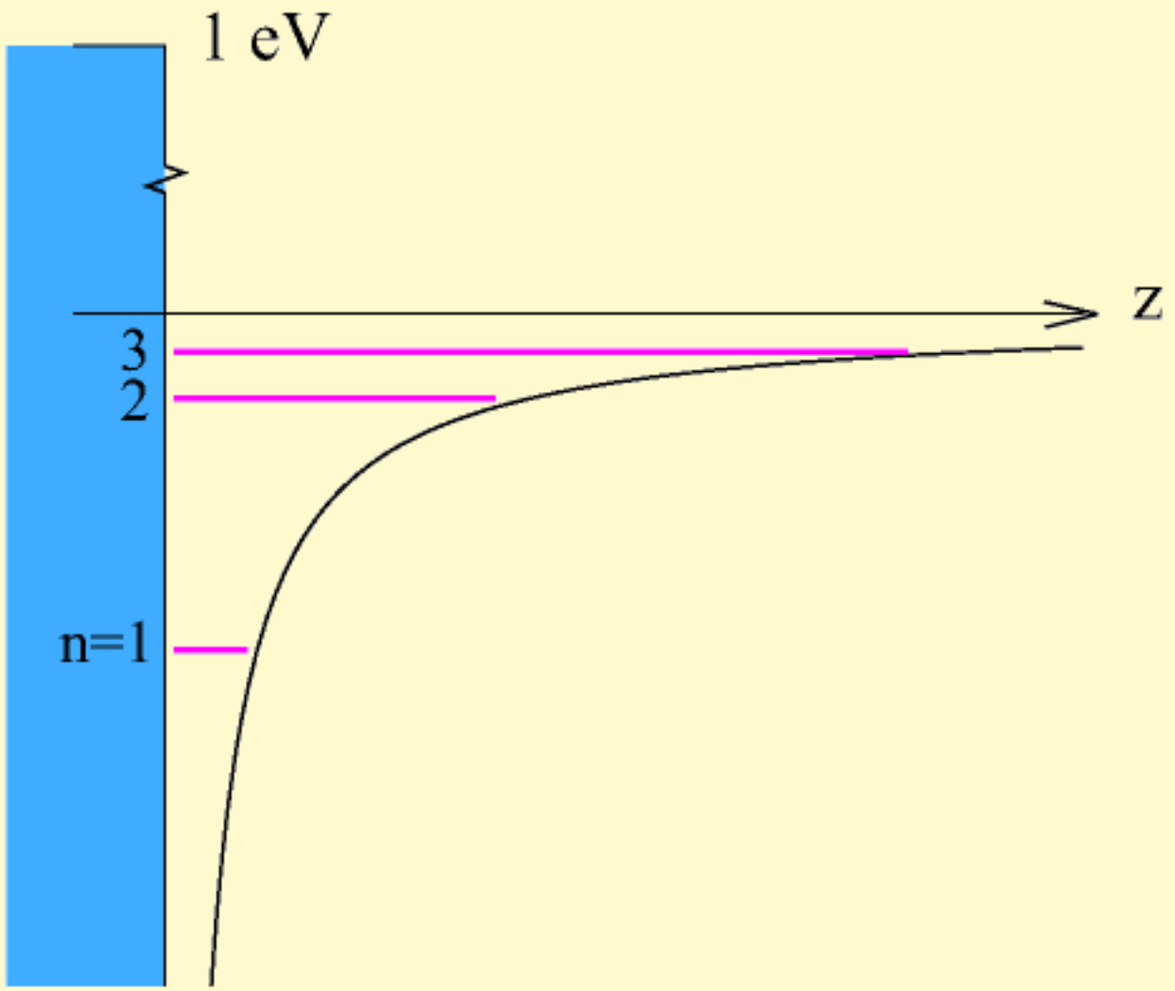
Outline

- Introduction
- Experiment
- Results
  - Microwave (MW) absorption induced hot-electron effect
  - Frequency shift and temperature bistability
  - Magnetoconductivity oscillation and conductivity vanishing
  - Spontaneous current oscillation
- Summary

Phys. Rev. Lett. 98, 235302 (2007), Phys. Rev. Lett. 103, 096801 (2009),
Phys. Rev. Lett. 103, 266808 (2009), Phys Rev. Lett. 105, 226801 (2010),
J. Phys. Soc. Jpn. 81 093601 (2012), J. Phys. Soc. Jpn. 82 043601 (2013),
J. Phys. Soc. Jpn. 82 075002 (2013).

Image potential

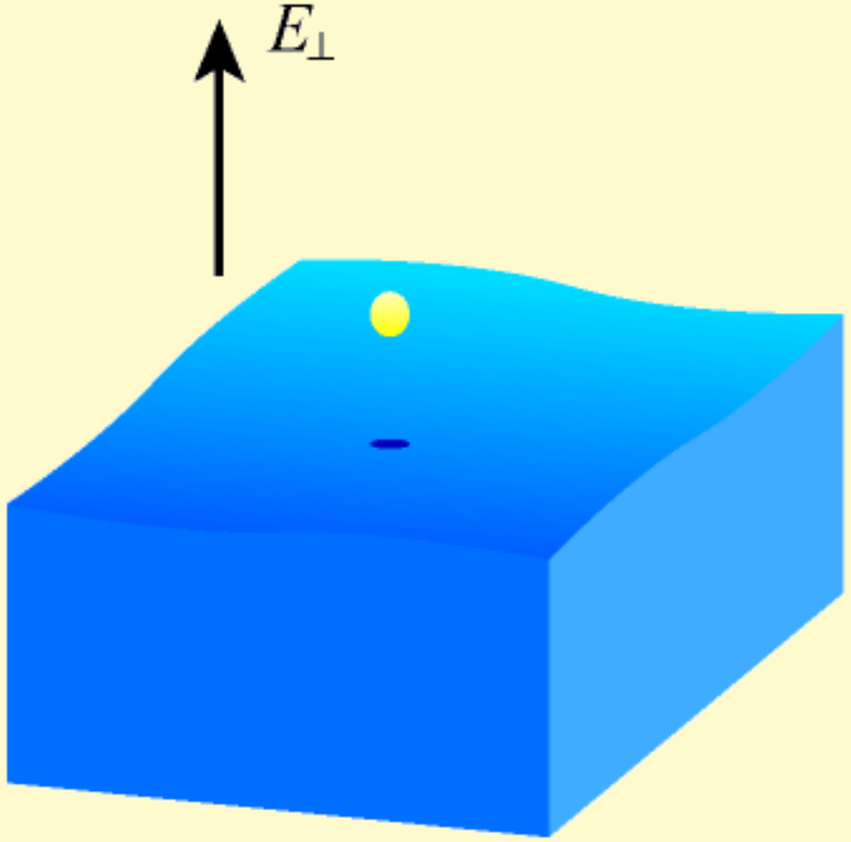


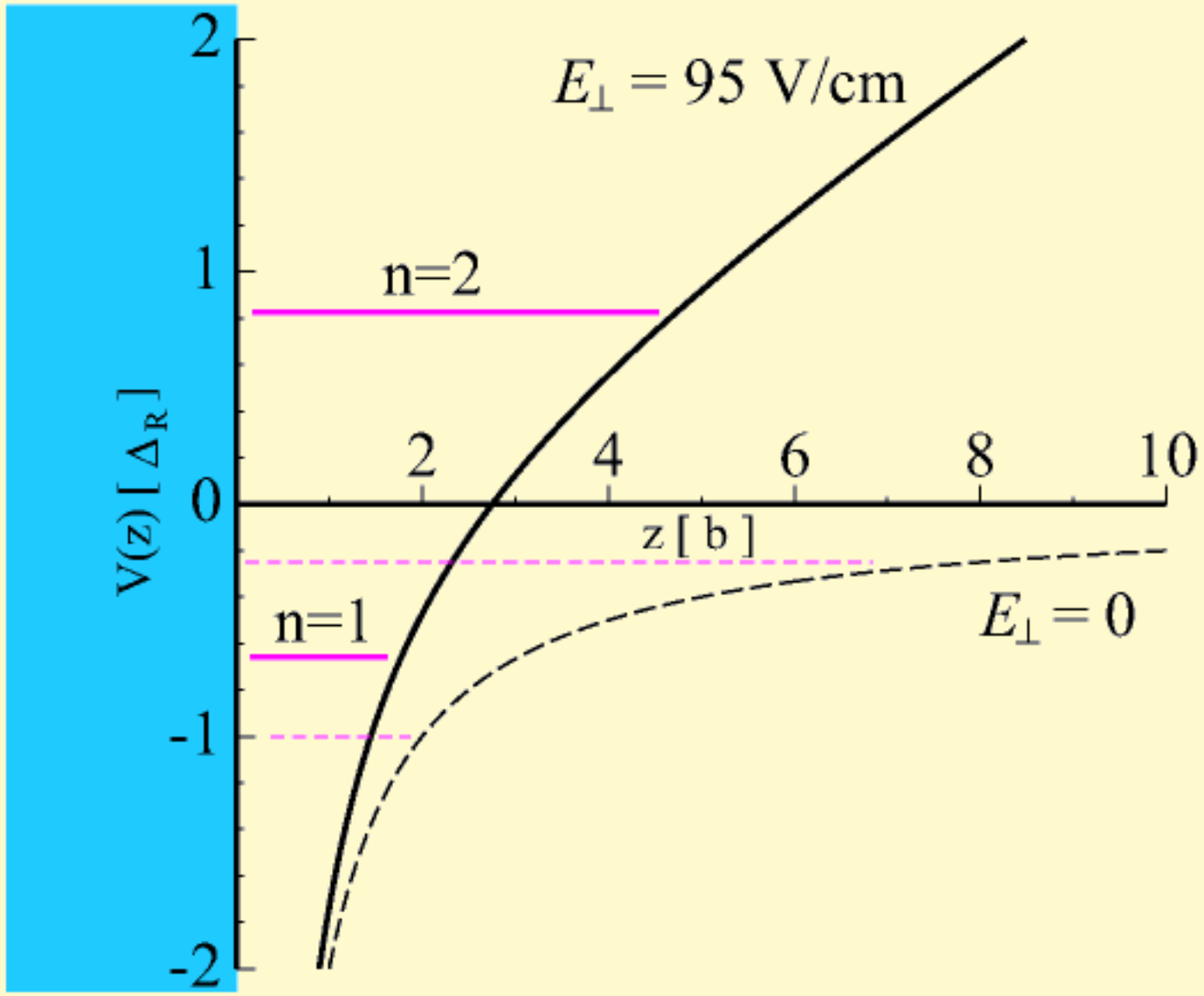


$$V(z) = -\frac{\Lambda e^2}{z}$$

$$\Lambda = \frac{1}{4}\frac{\epsilon - 1}{\epsilon + 1} \approx 0.0052 \quad (^3\mathrm{He})$$

Surface states



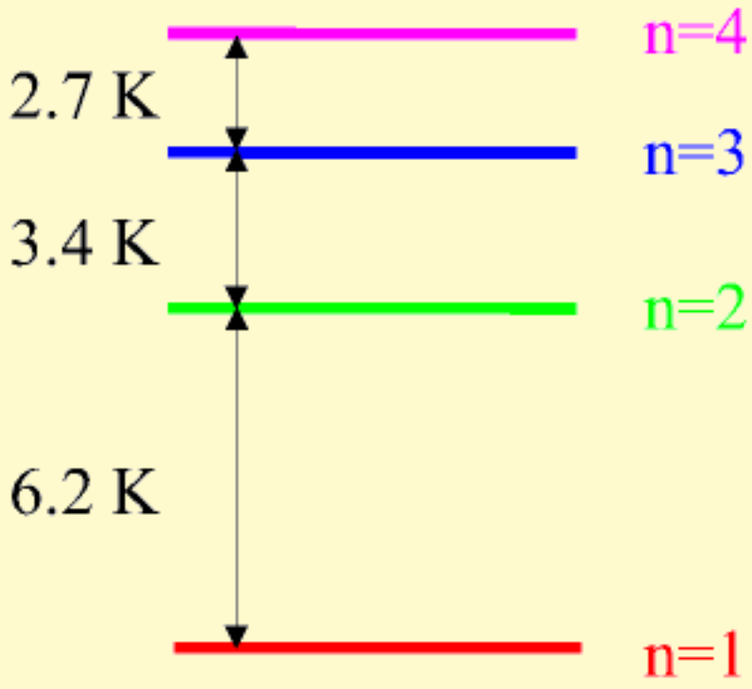


$$\epsilon = \epsilon_\perp + \frac{p_\parallel^2}{2m}$$

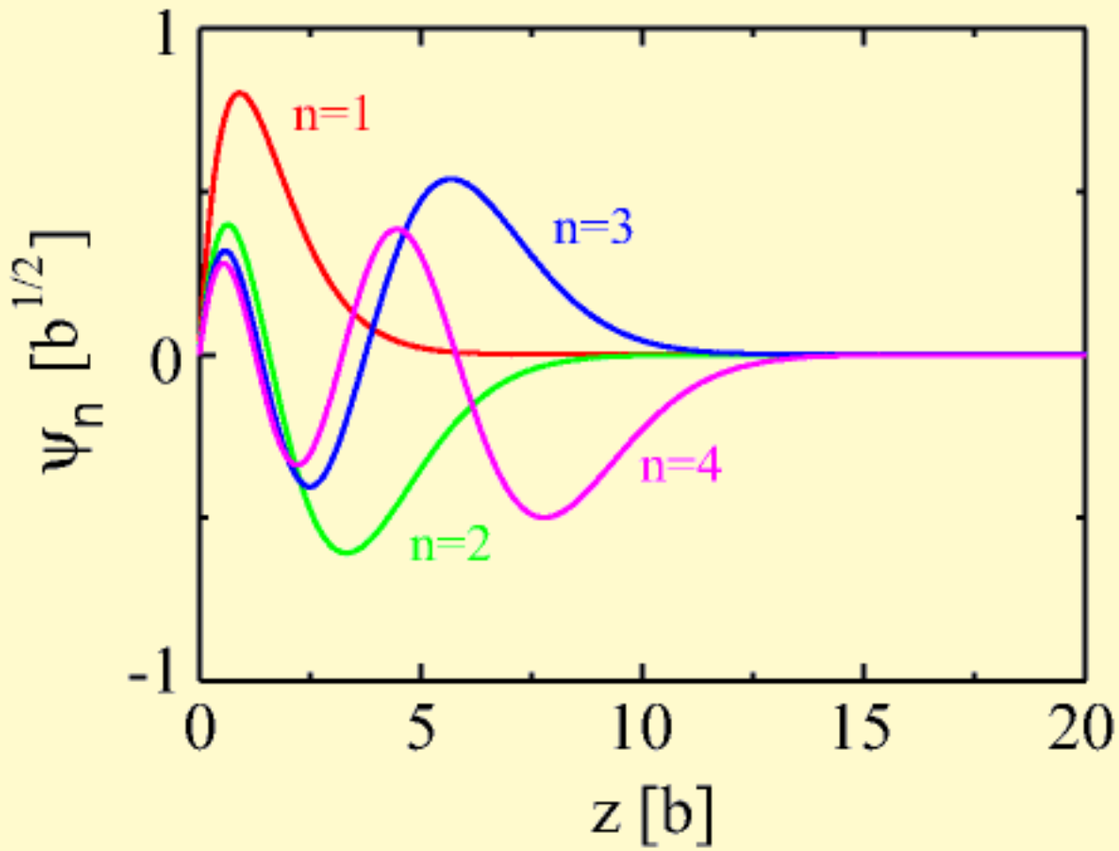
$$V(z) = -\frac{\Lambda e^2}{z} + eE_\perp z$$

Wave functions

$$\left[-\frac{\hbar^2}{2m}\nabla_z^2 - \frac{\Lambda e^2}{z} + eE_\perp z\right]\psi_n(z) = \epsilon_n \psi_n(z)$$



$E_\perp$= 95 V/cm

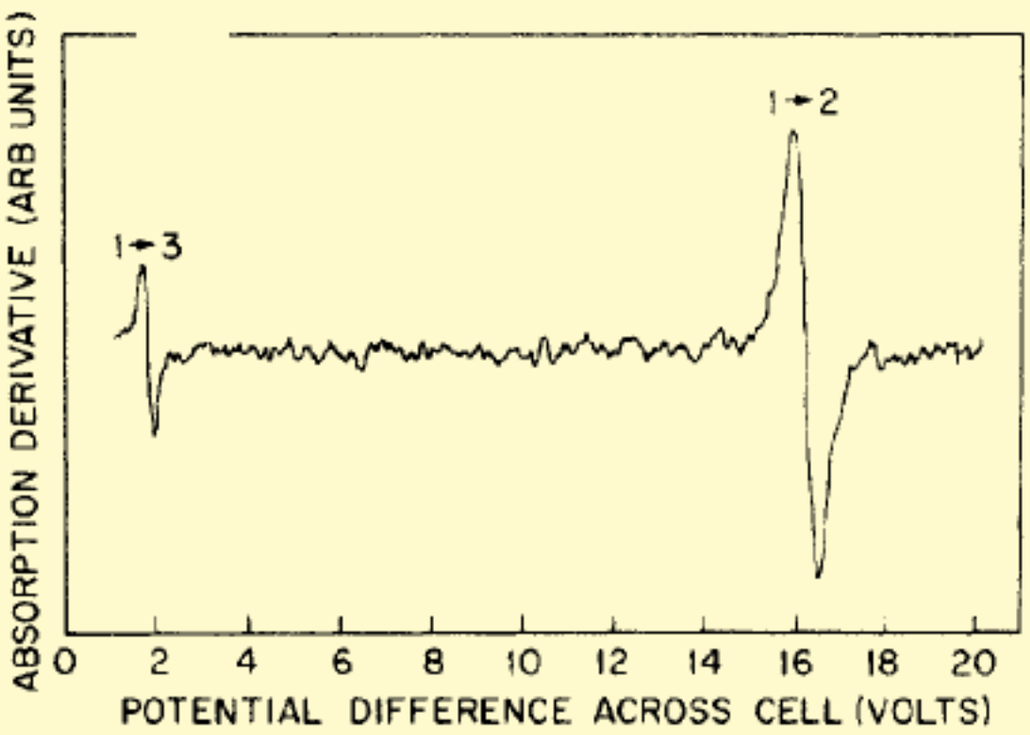


Experimental evidence for 2D electrons

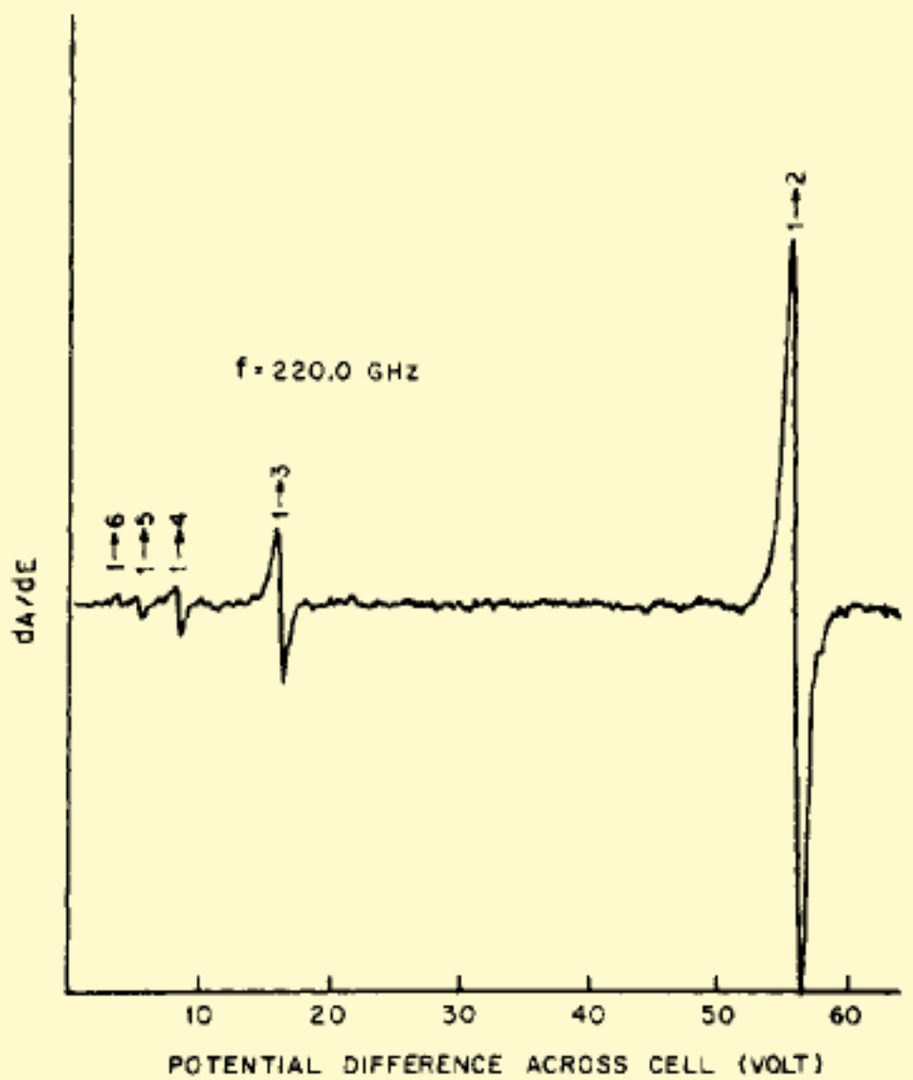
Direct Spectroscopic Observation of Electrons in Image-Potential States Outside Liquid Helium

C. C. Grimes and T. R. Brown
Bell Laboratories, Murray Hill, New Jersey 07974
(Received 26 November 1973)
Phys. Rev. Lett. 32 (1974) 280.

160 GHz

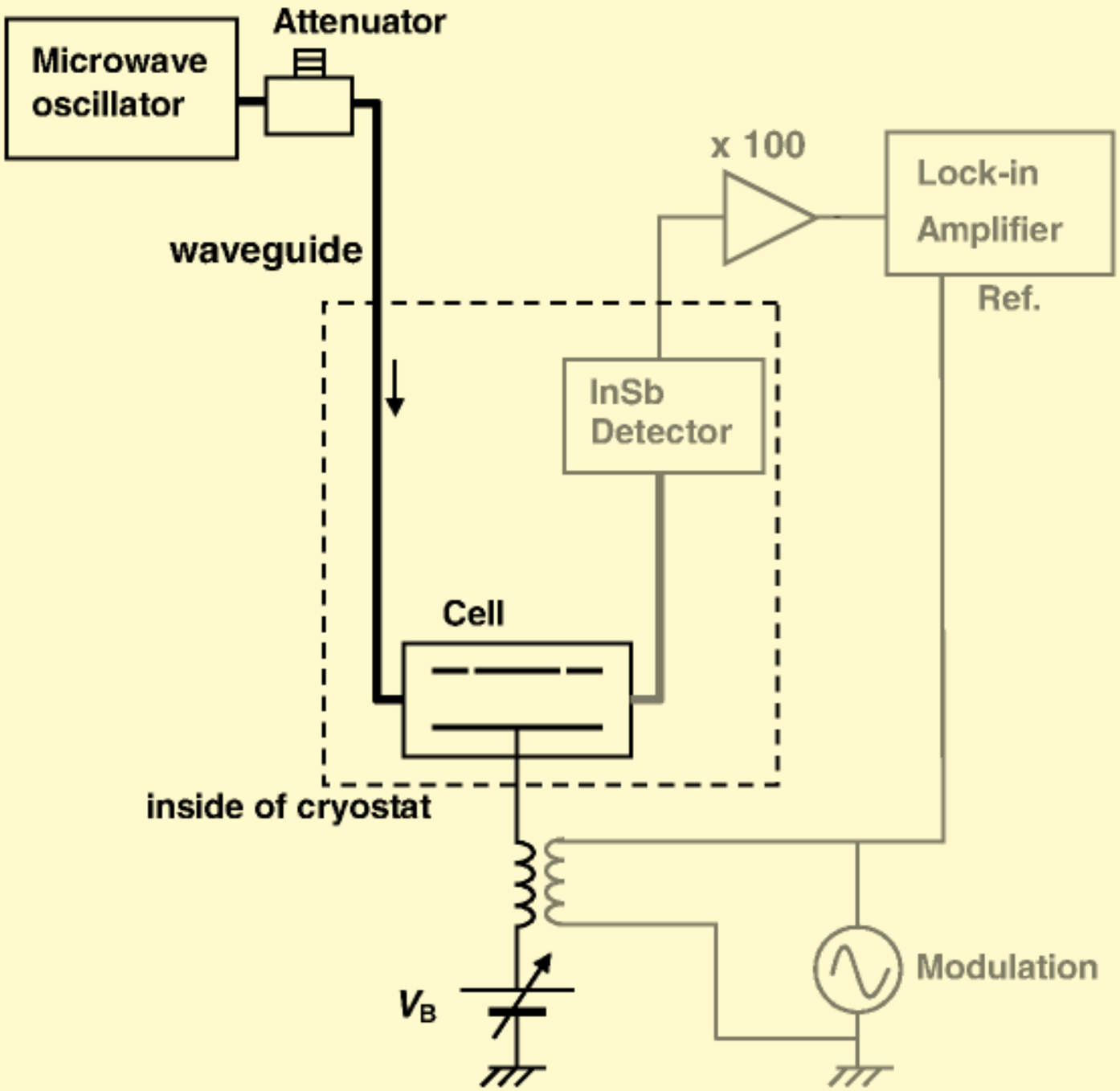


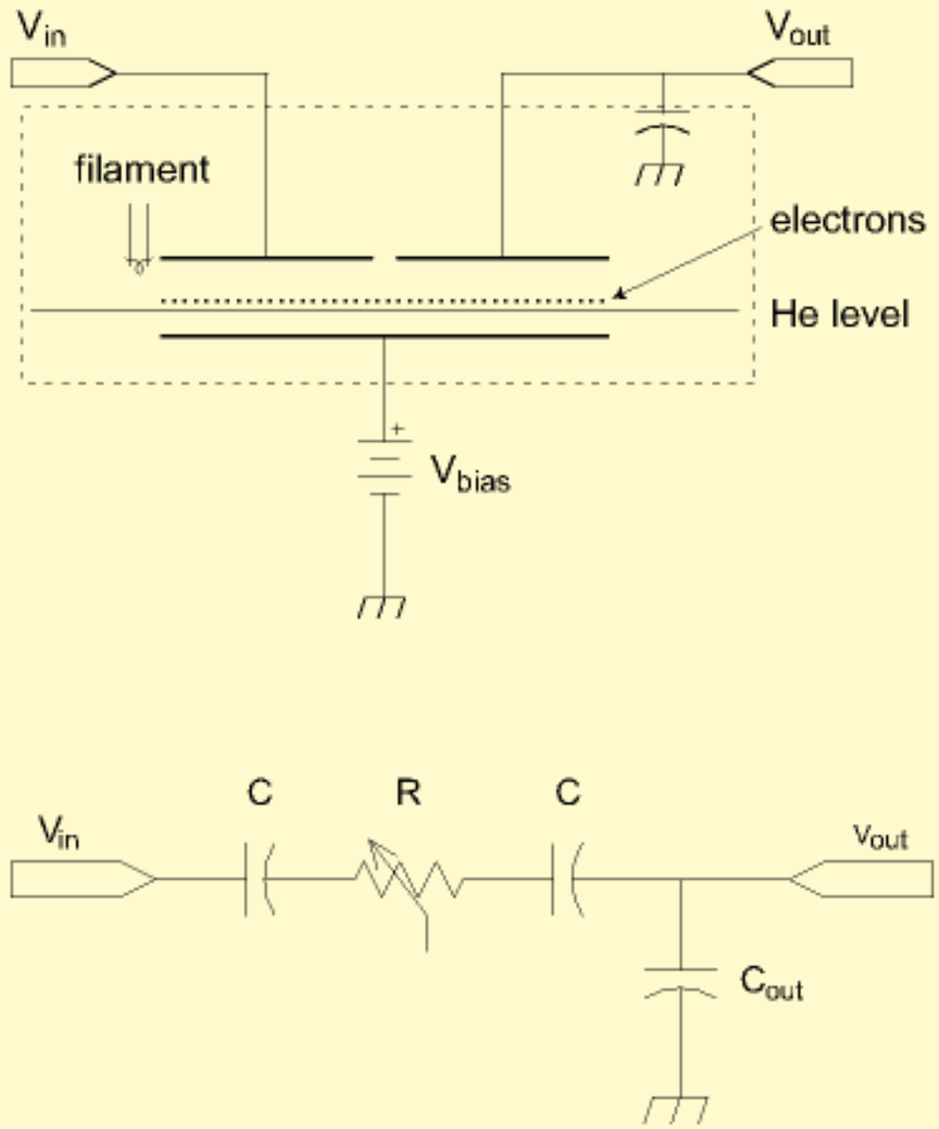
220 GHz



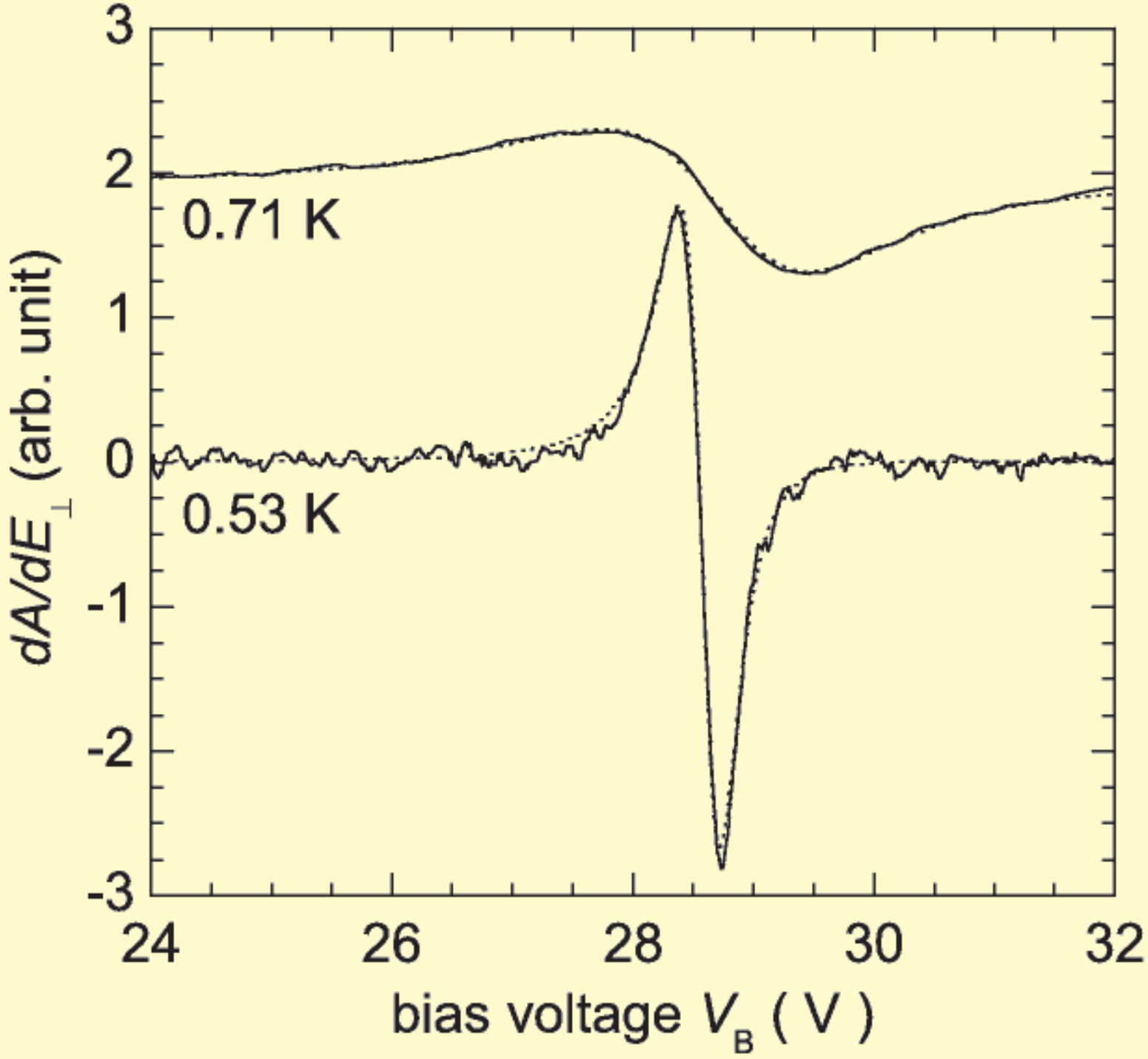
Experimental block diagram

E. Collin et al.: Phys. Rev. Lett. 89 (2002) 245301.

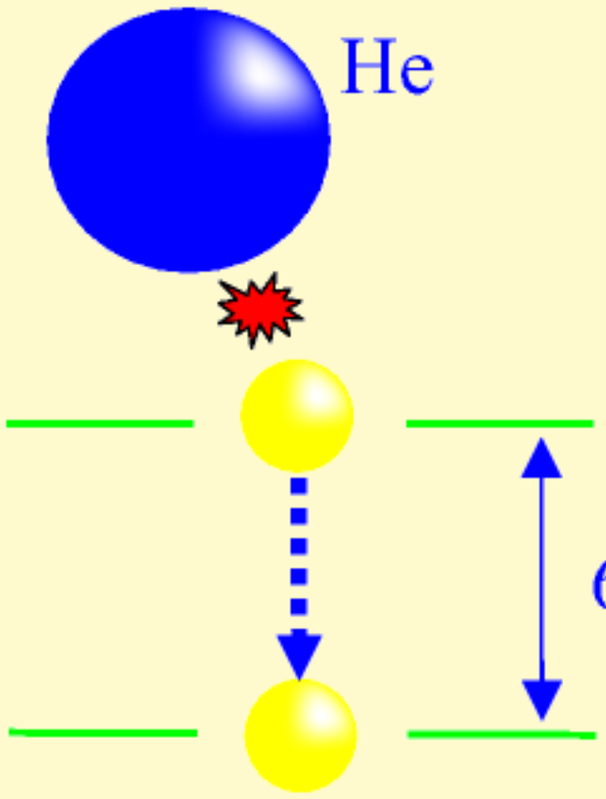


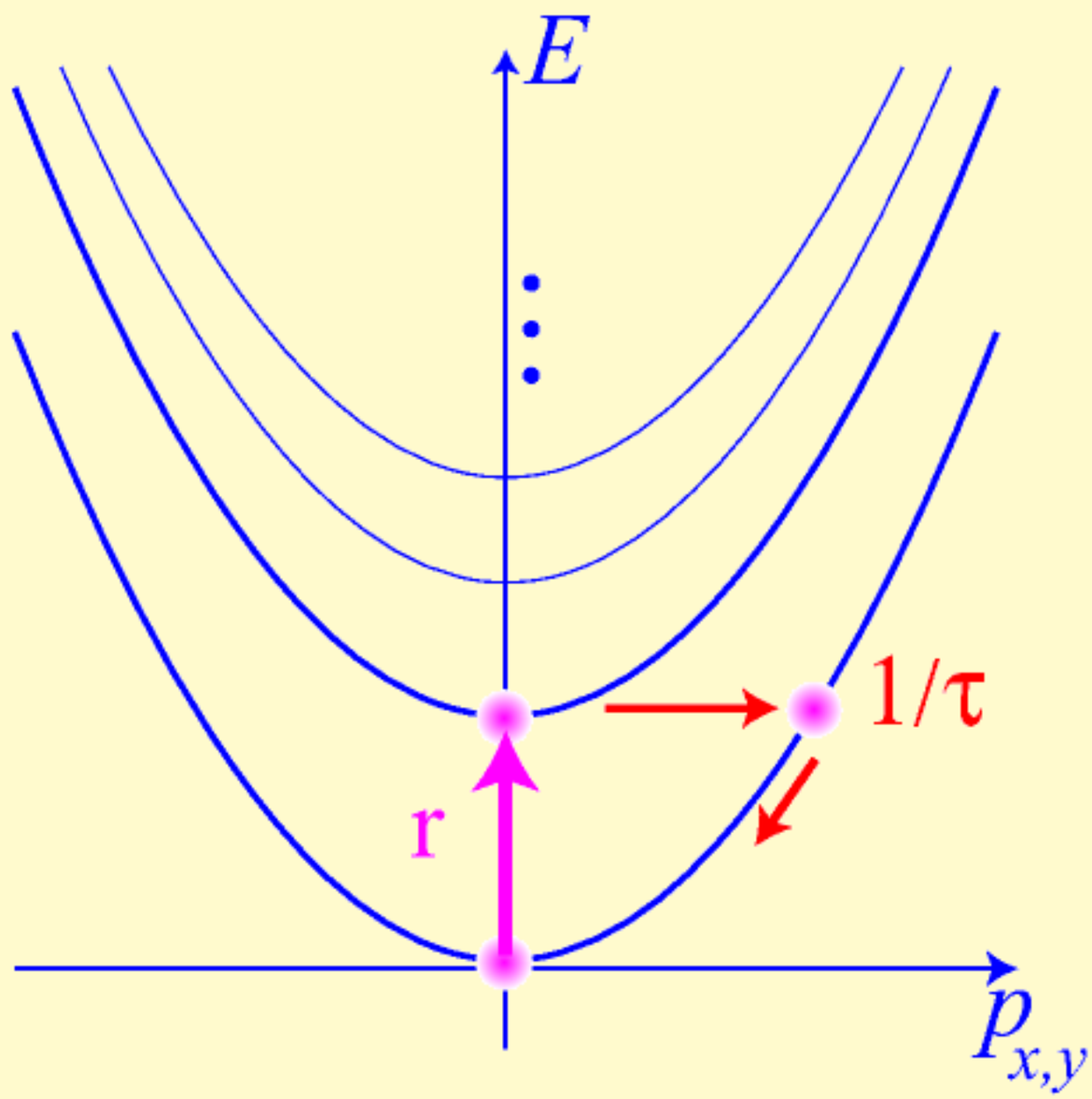


Absorption signal



Relaxation dynamics



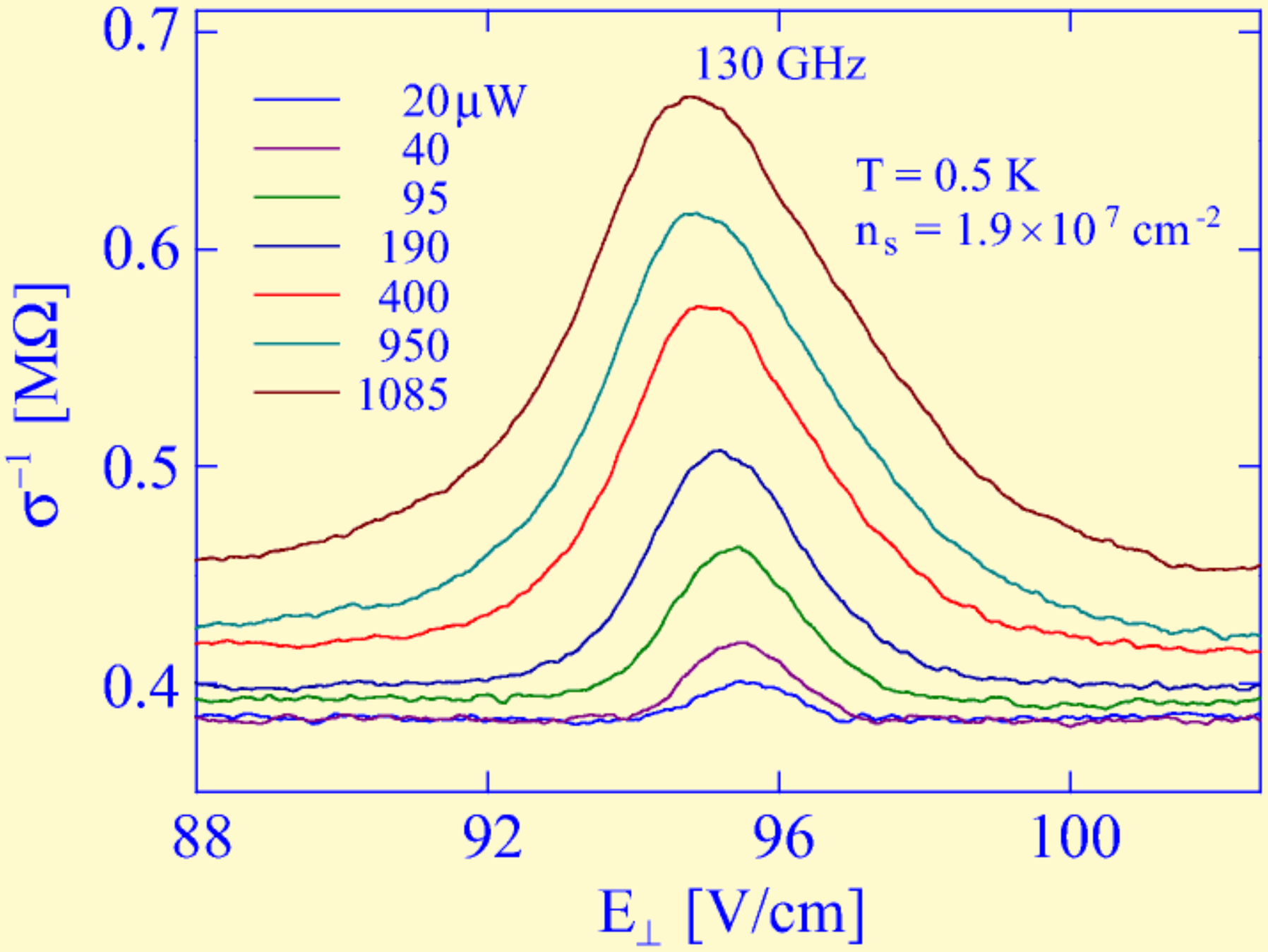


Total energy E_n

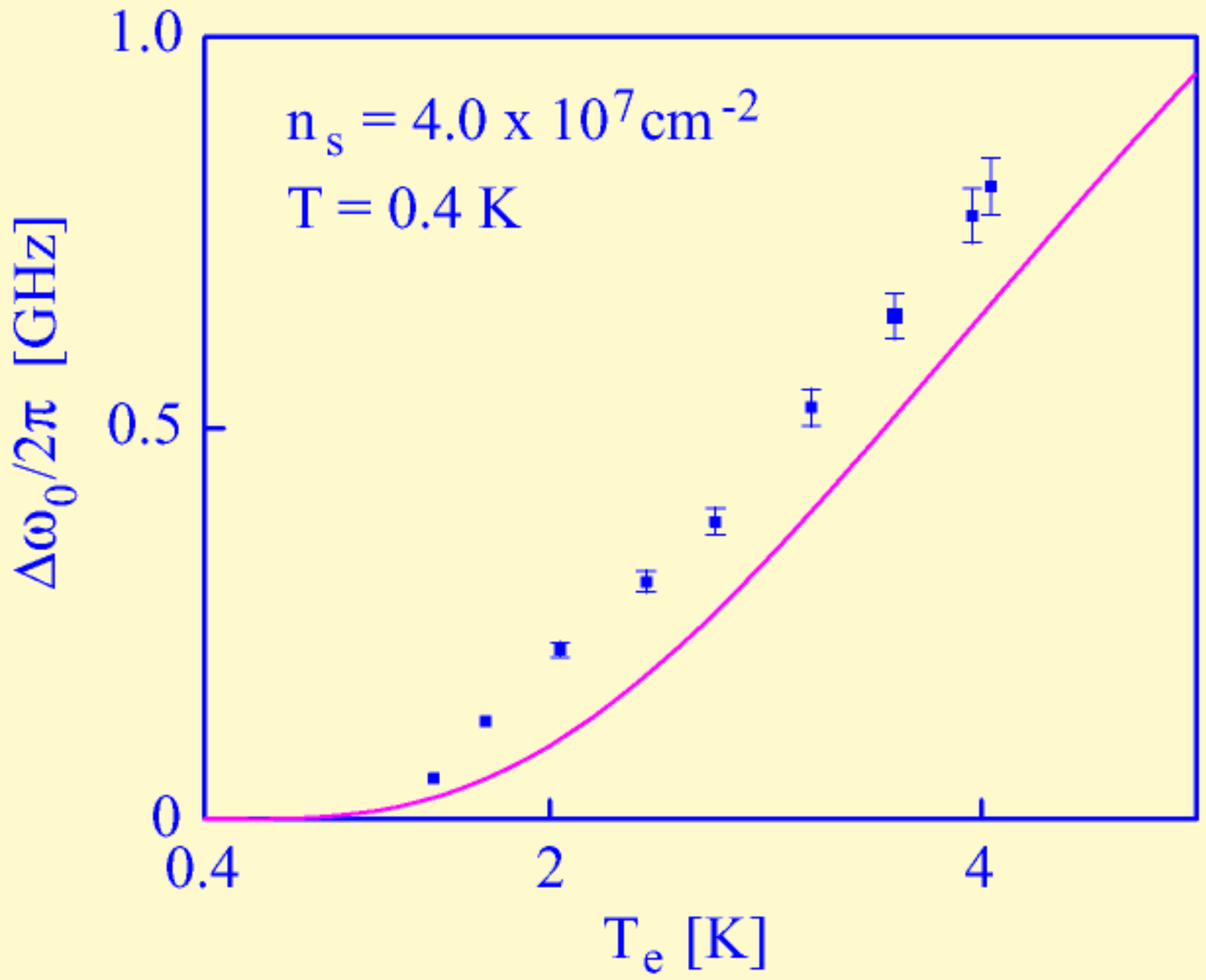
$$E_n = \epsilon_n + \frac{p_\parallel^2}{2m}$$

Resistivity detected MW absorption

Phys. Rev. Lett. 98, 235302 (2007): Ultrahot electrons

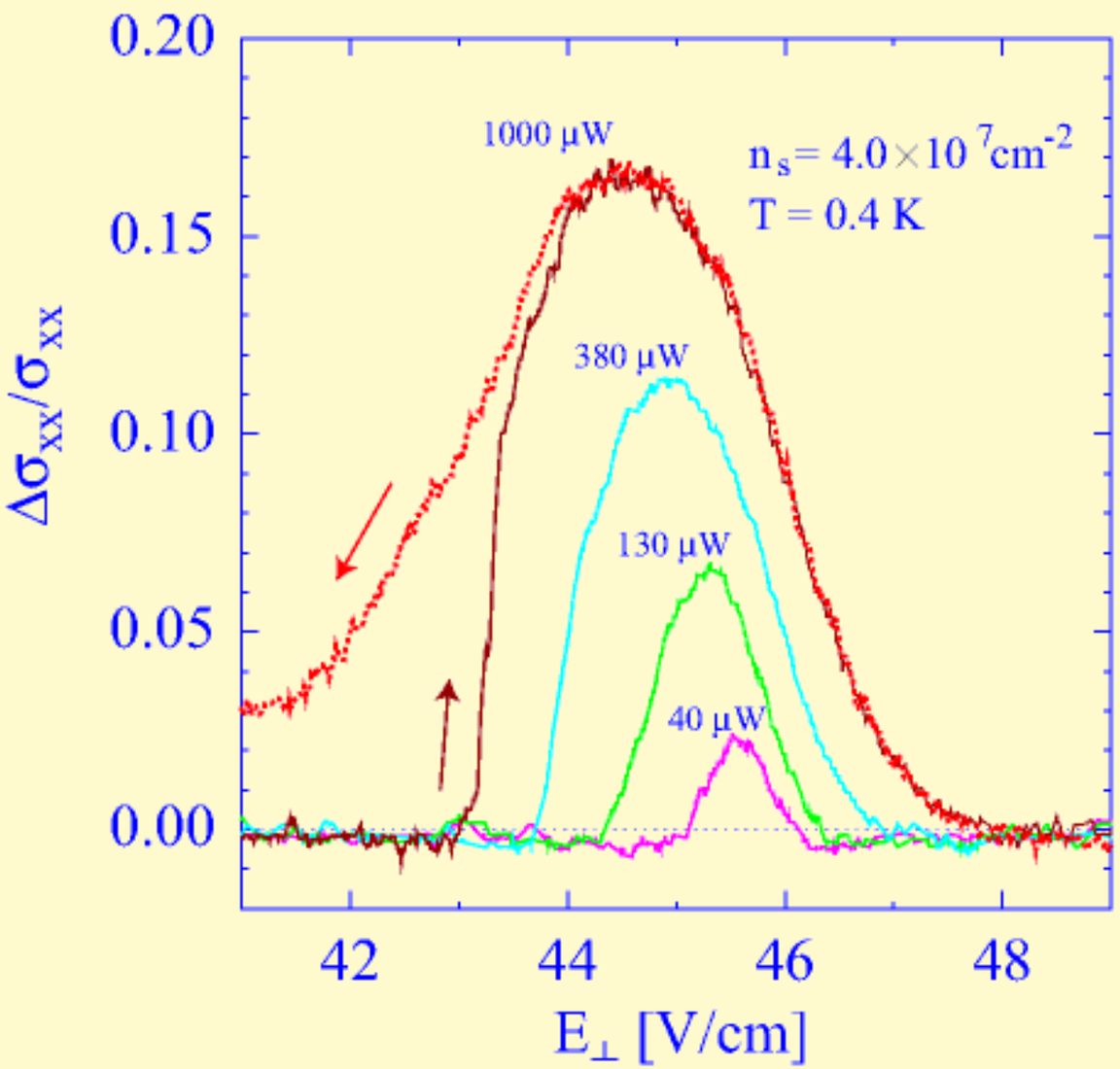


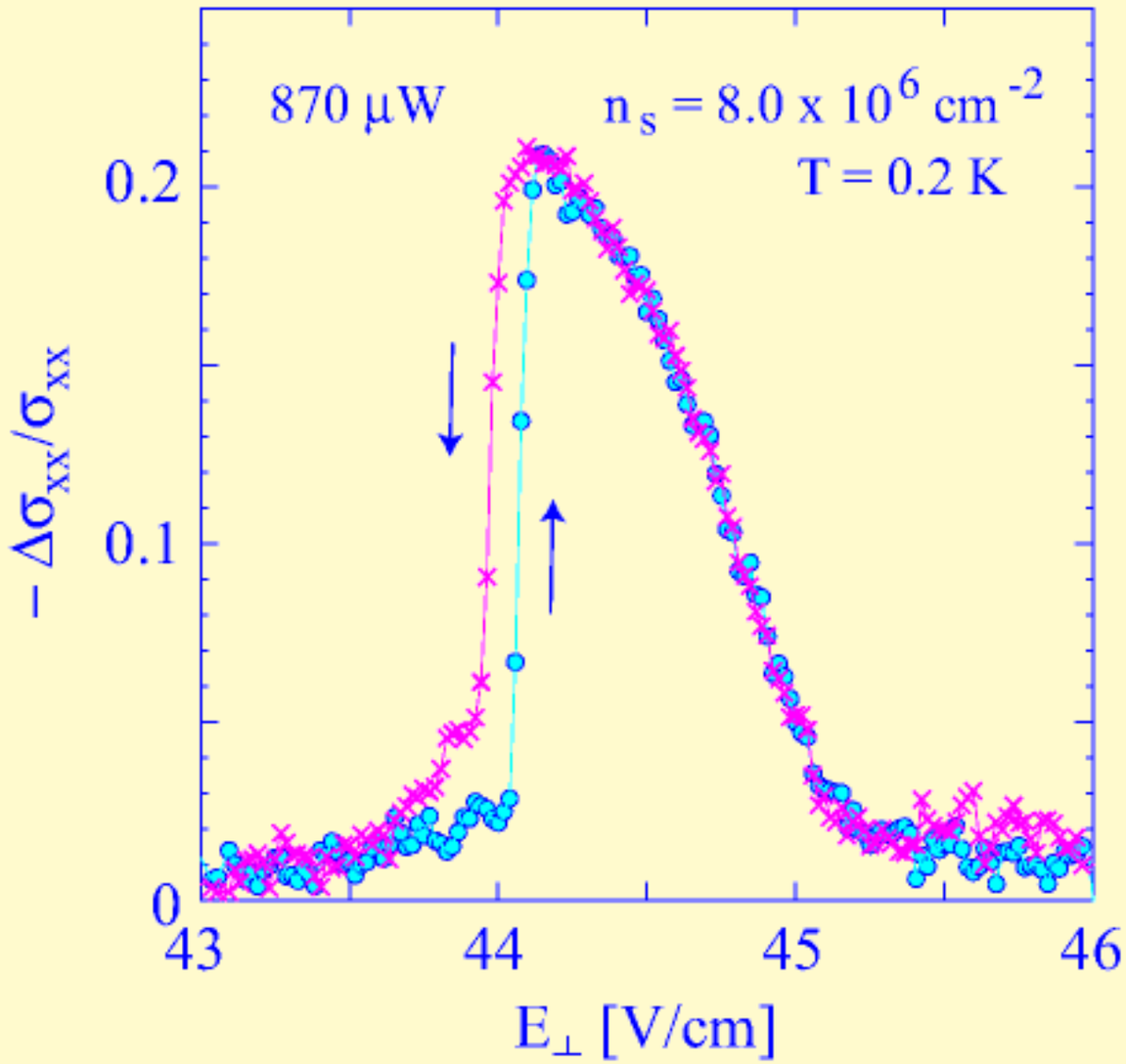
Frequency shift vs electron temperature



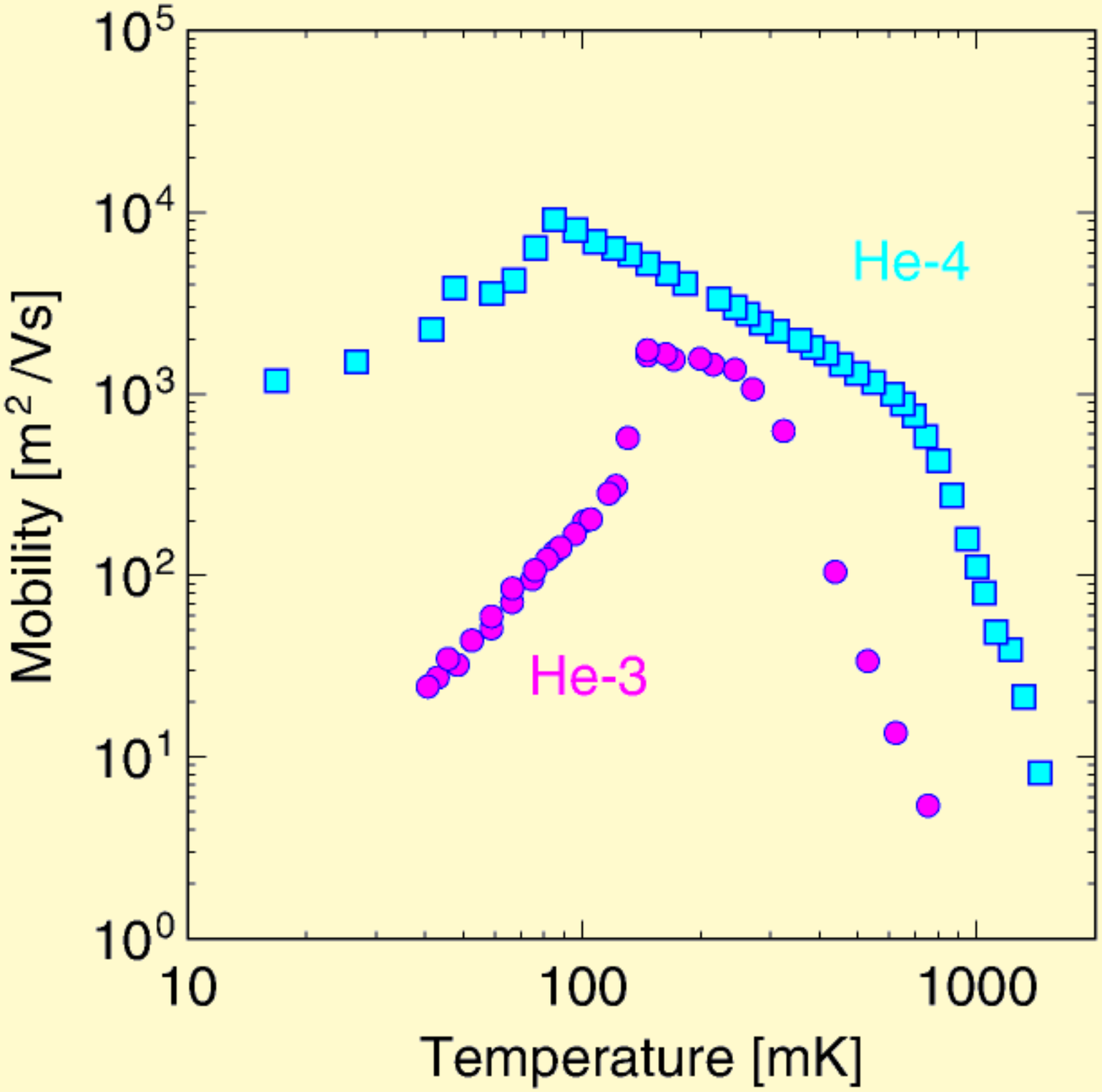
Hysteresis

Phys. Rev. Lett. 103, 096801 (2009): Optical bistability



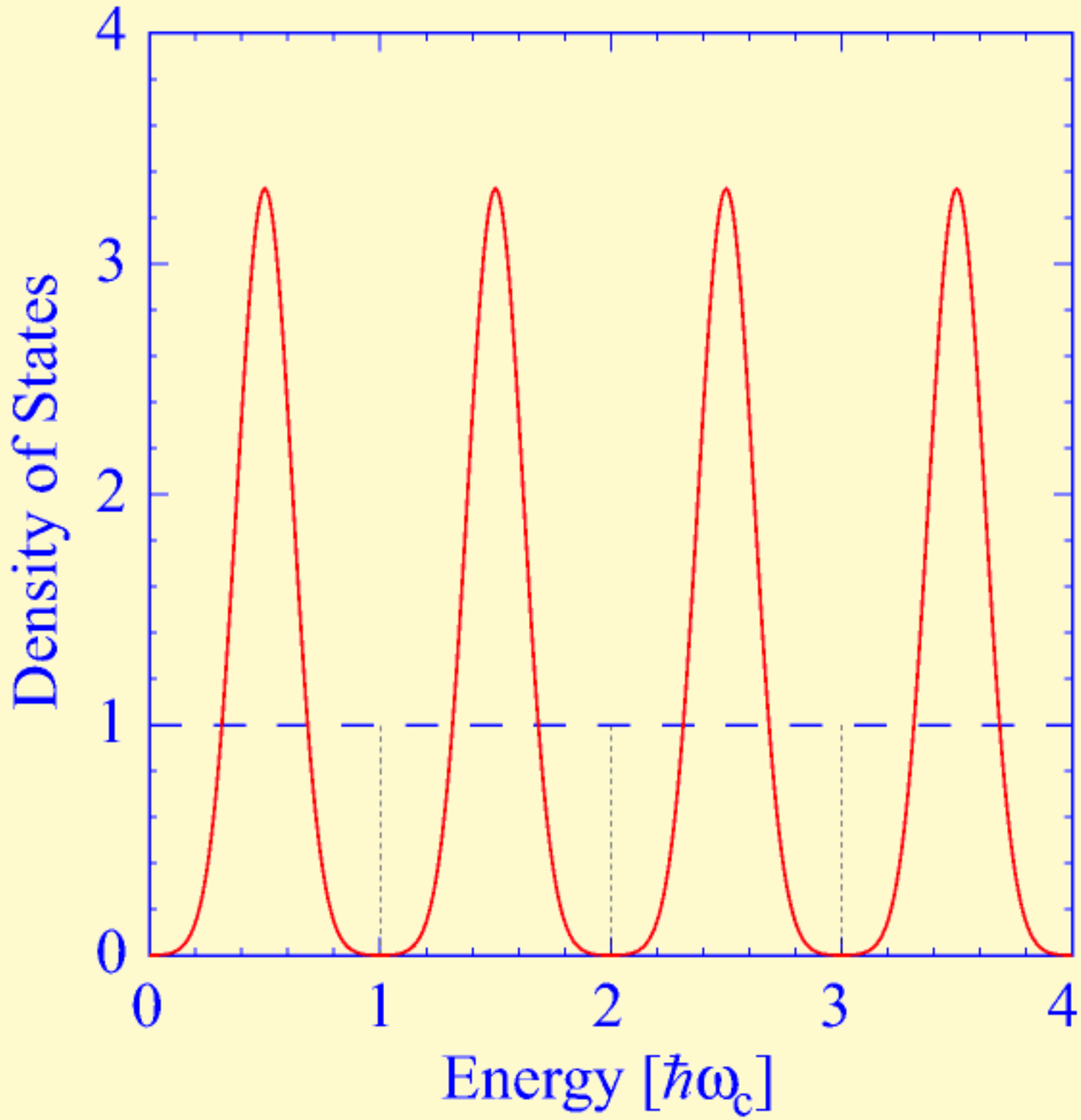


High mobility

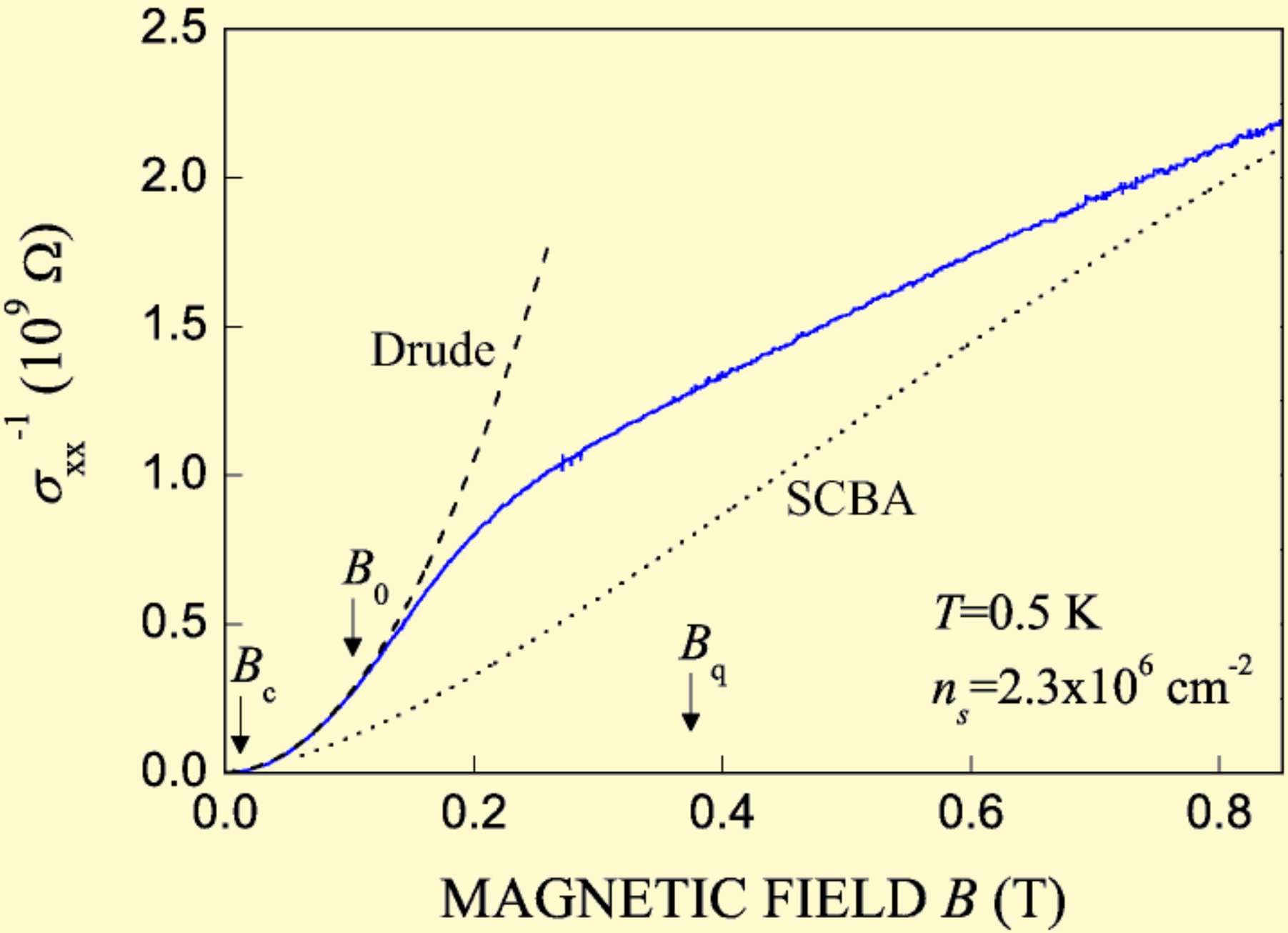


Landau quantization (magnetic field)

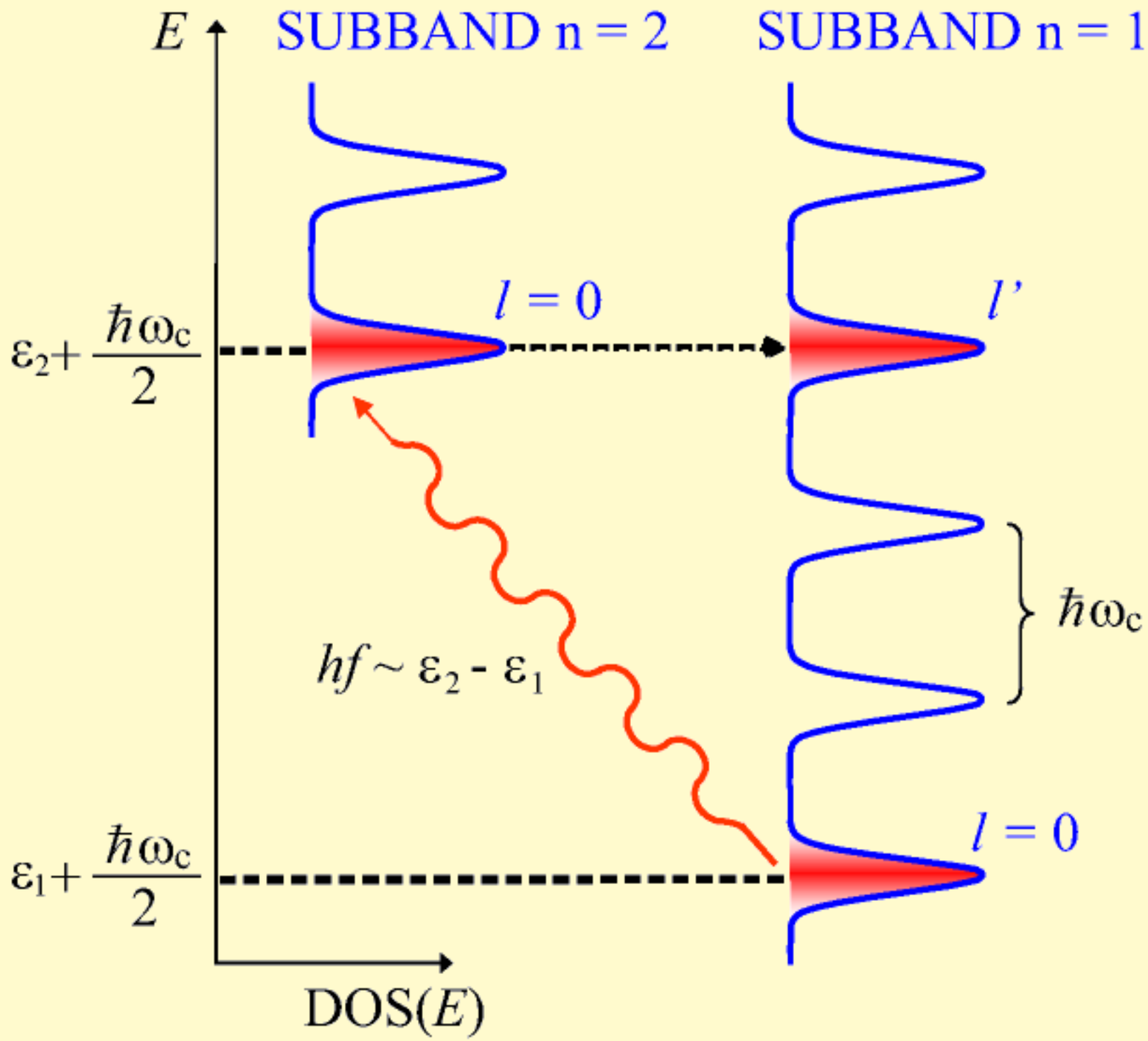
$$\omega_c = \frac{eB}{m}$$



Lea-Dykman Magnetoresistance

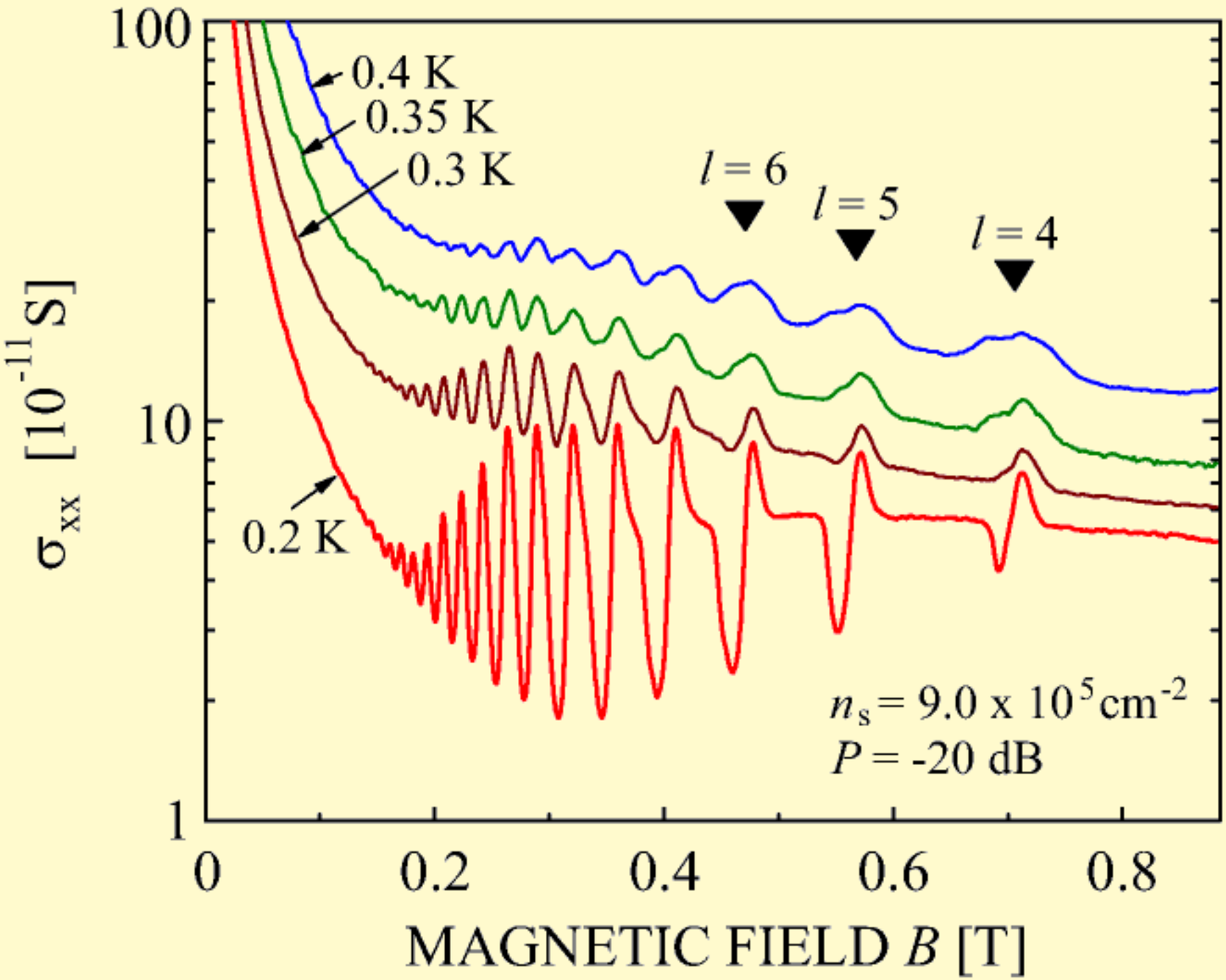


Intersubband scattering



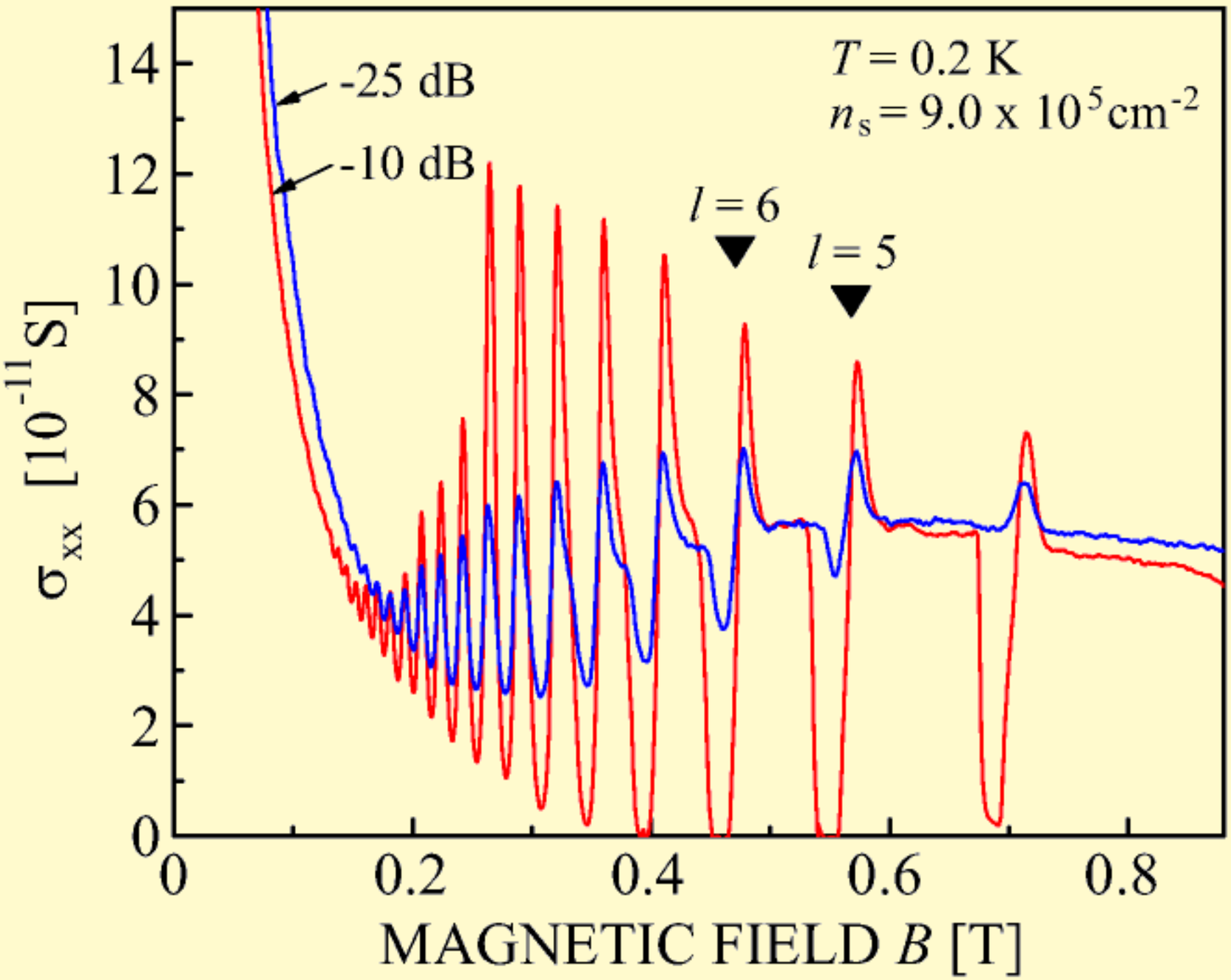
Magnetooscillation

Phys. Rev. Lett. 103, 266808 (2009)



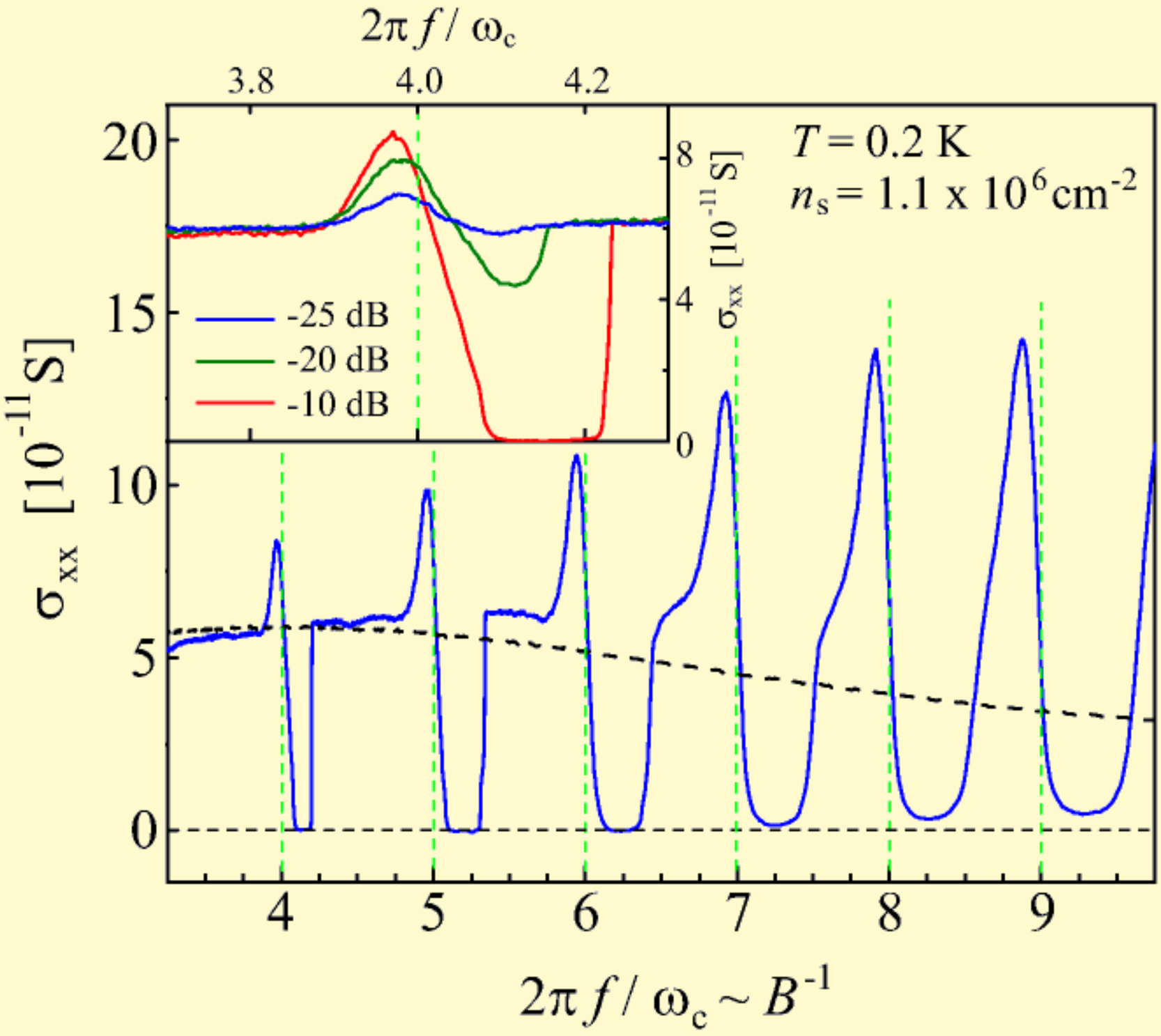
Zero conductance

Phys Rev. Lett. 105, 226801 (2010)



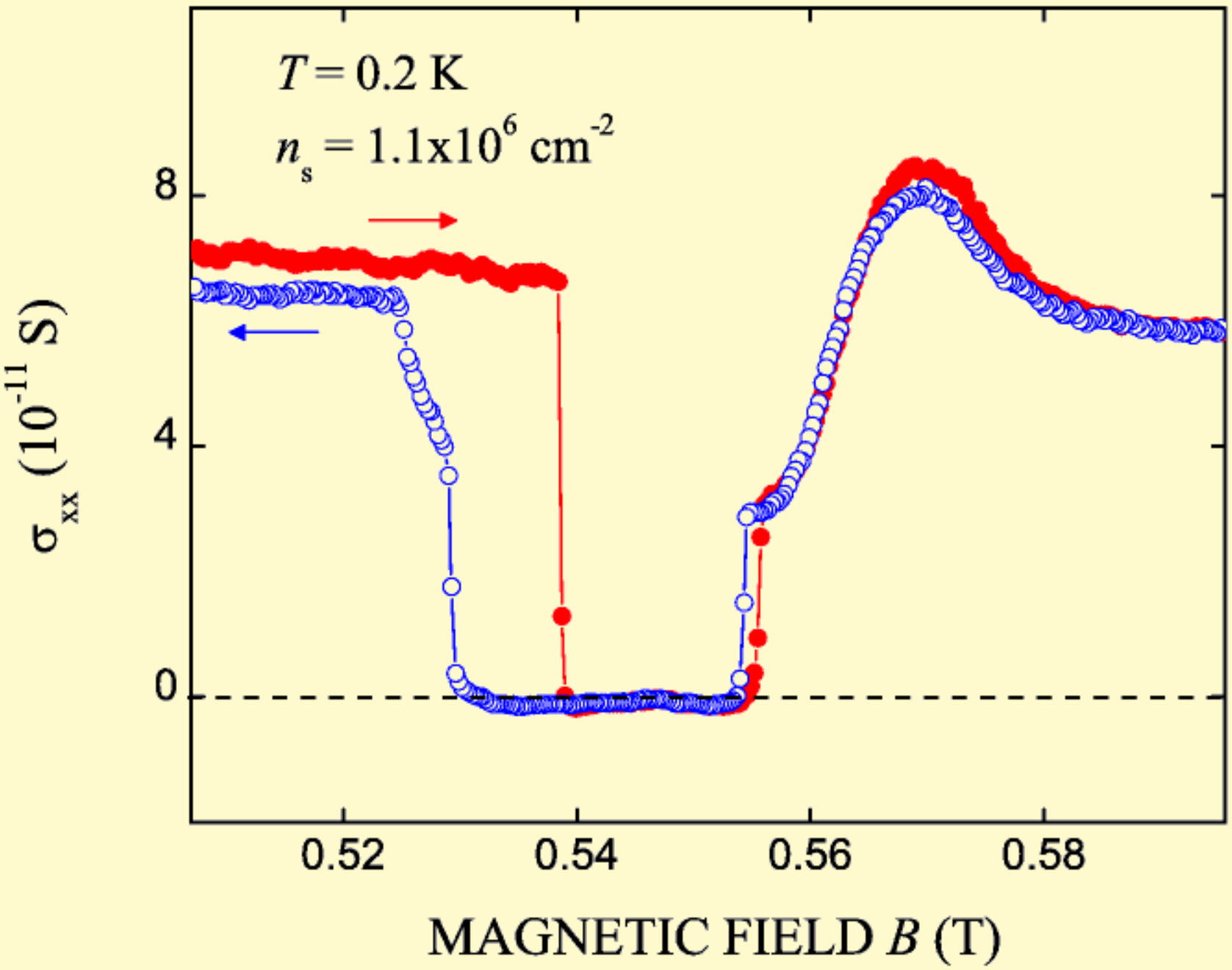
cf. Mani et al.: Nature (London) 420, 646 (2002).
Zudov, et al.: Phys. Rev. Lett. 90, 046807 (2003).

Position of zero conductance



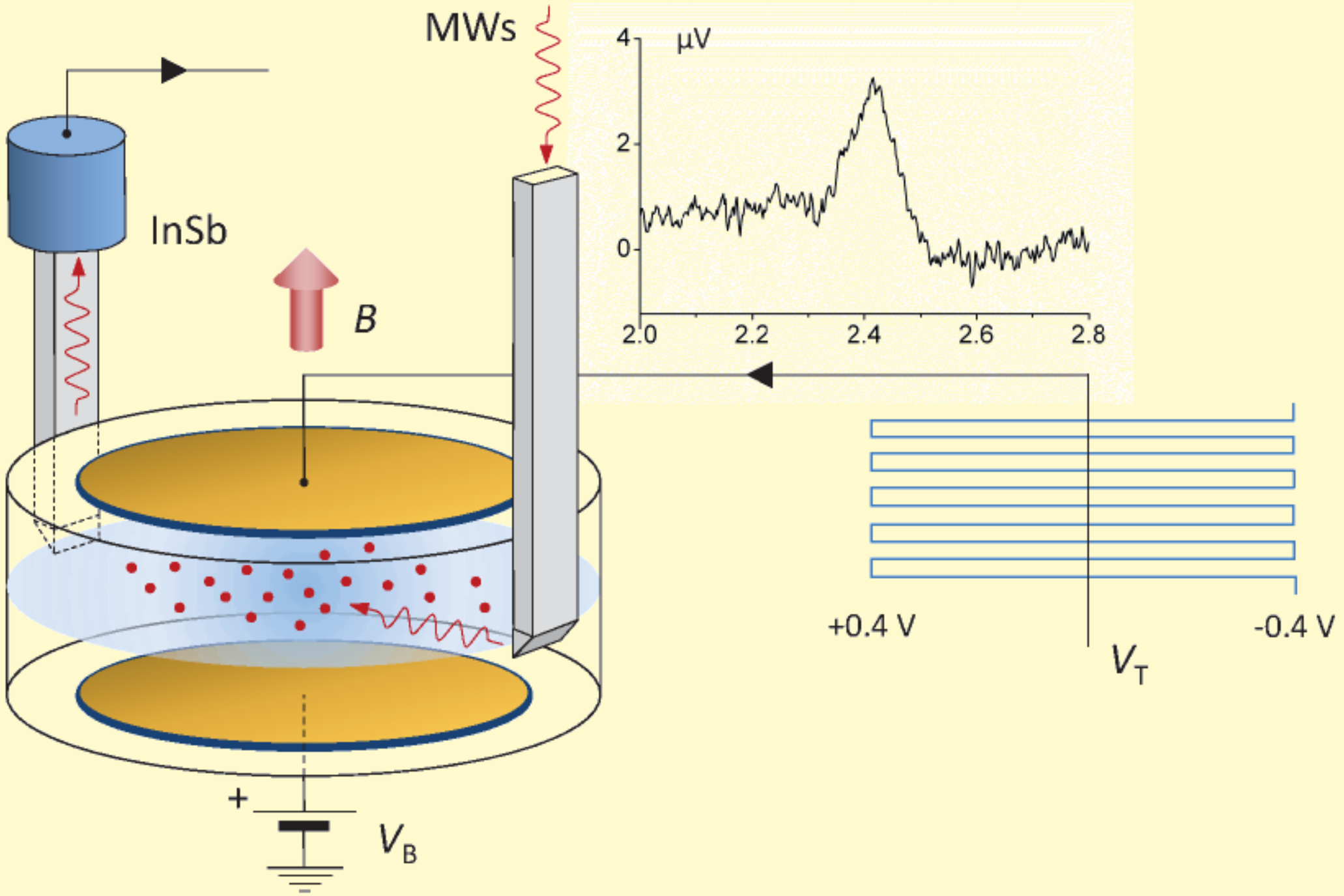
Yu. P. Monarkha, Fiz. Nizk. Temp. 37, 108 (2011).

Hysteresis

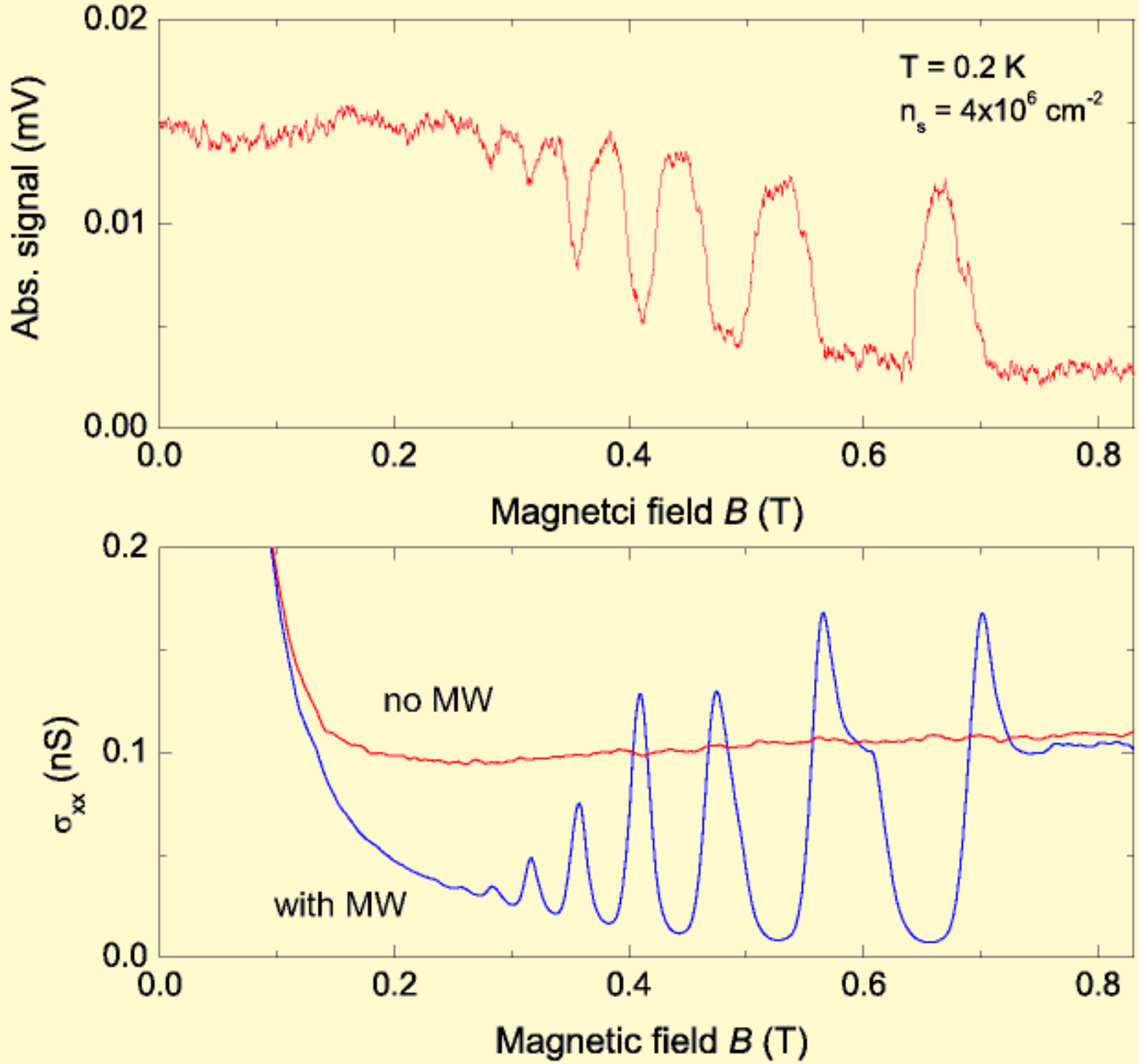

$T = 0.2$ K
$n_s = 1.1\text{x}10^6$ cm^{-2}
8
4
0
σ_{xx} (10^{-11} S)
0.52
0.54
0.56
0.58
MAGNETIC FIELD B (T)

MW Absorption

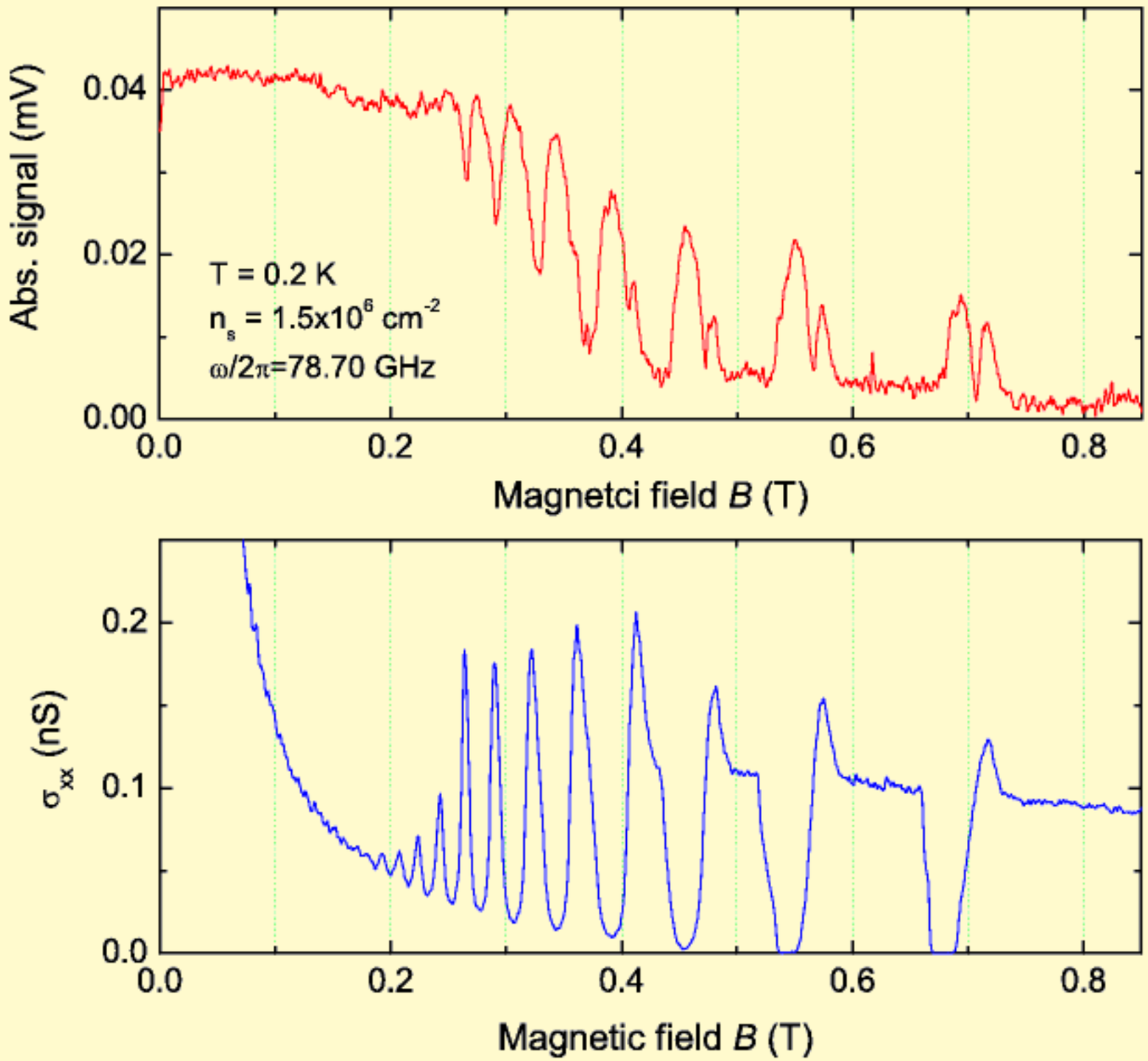
J. Phys. Soc. Jpn. 82 043601 (2013)



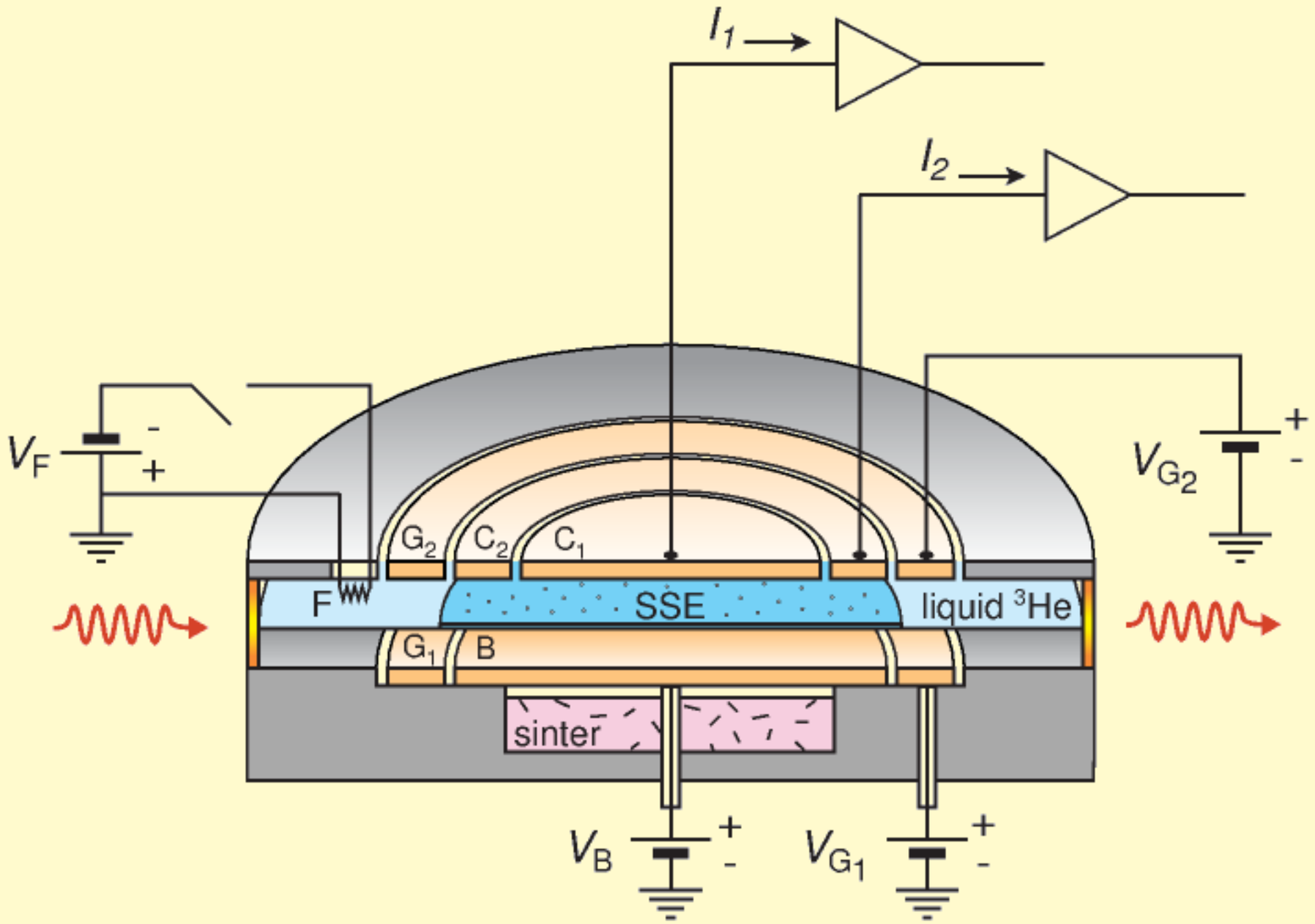
MW Absorption measurement



Low density (ZRS)

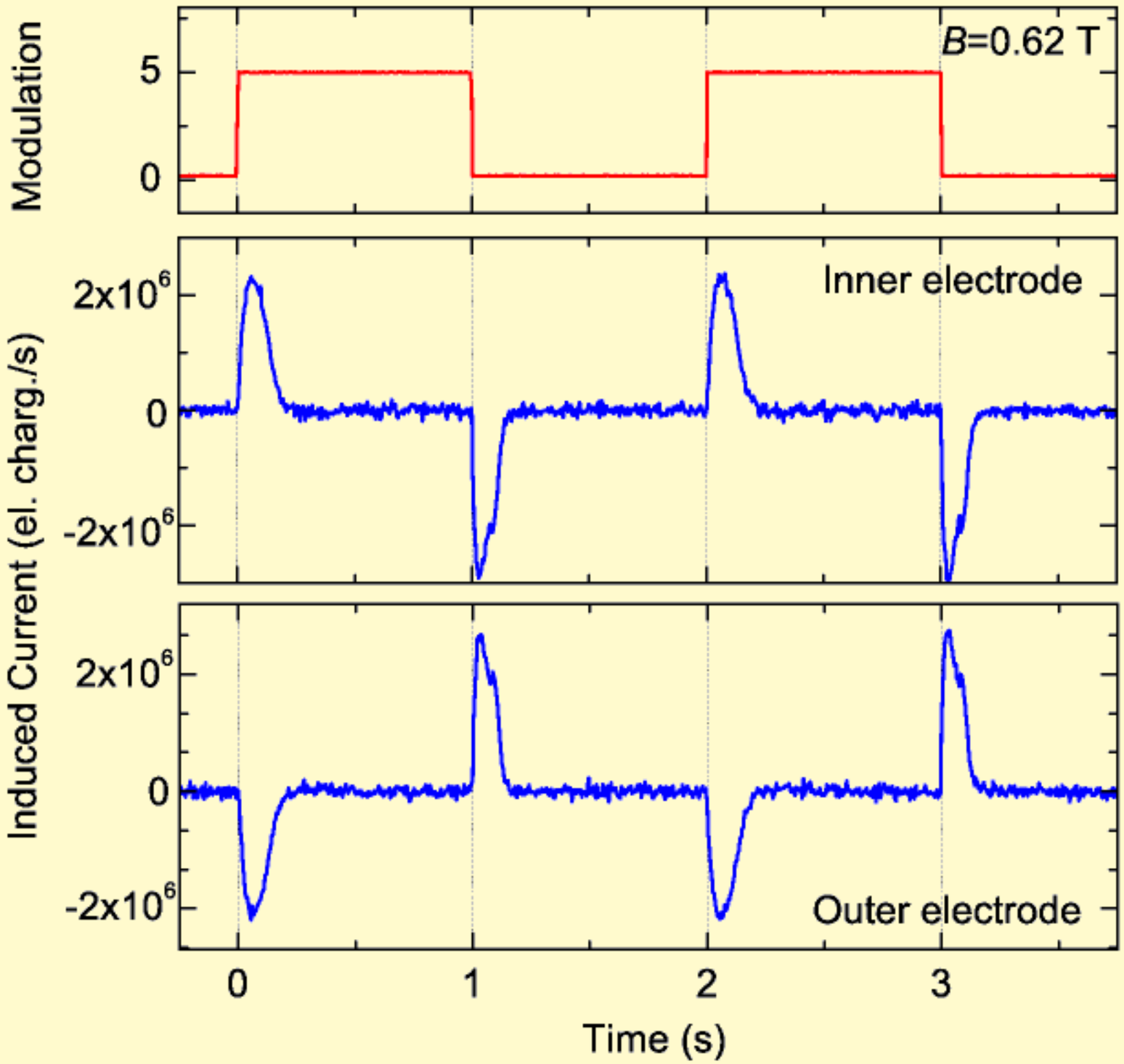


Experimental cell for photovoltaic effect

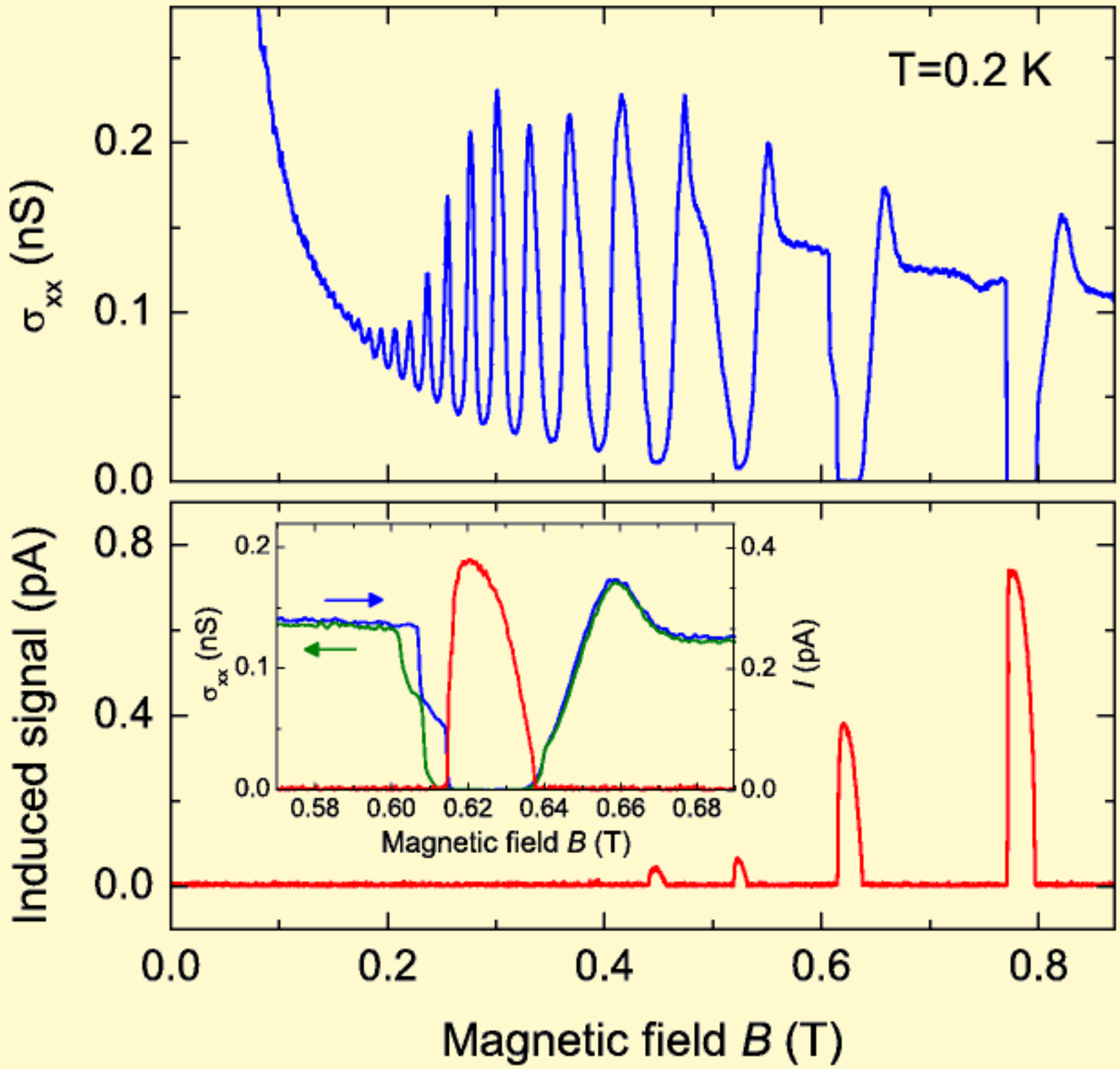


MW induced current (averaged)

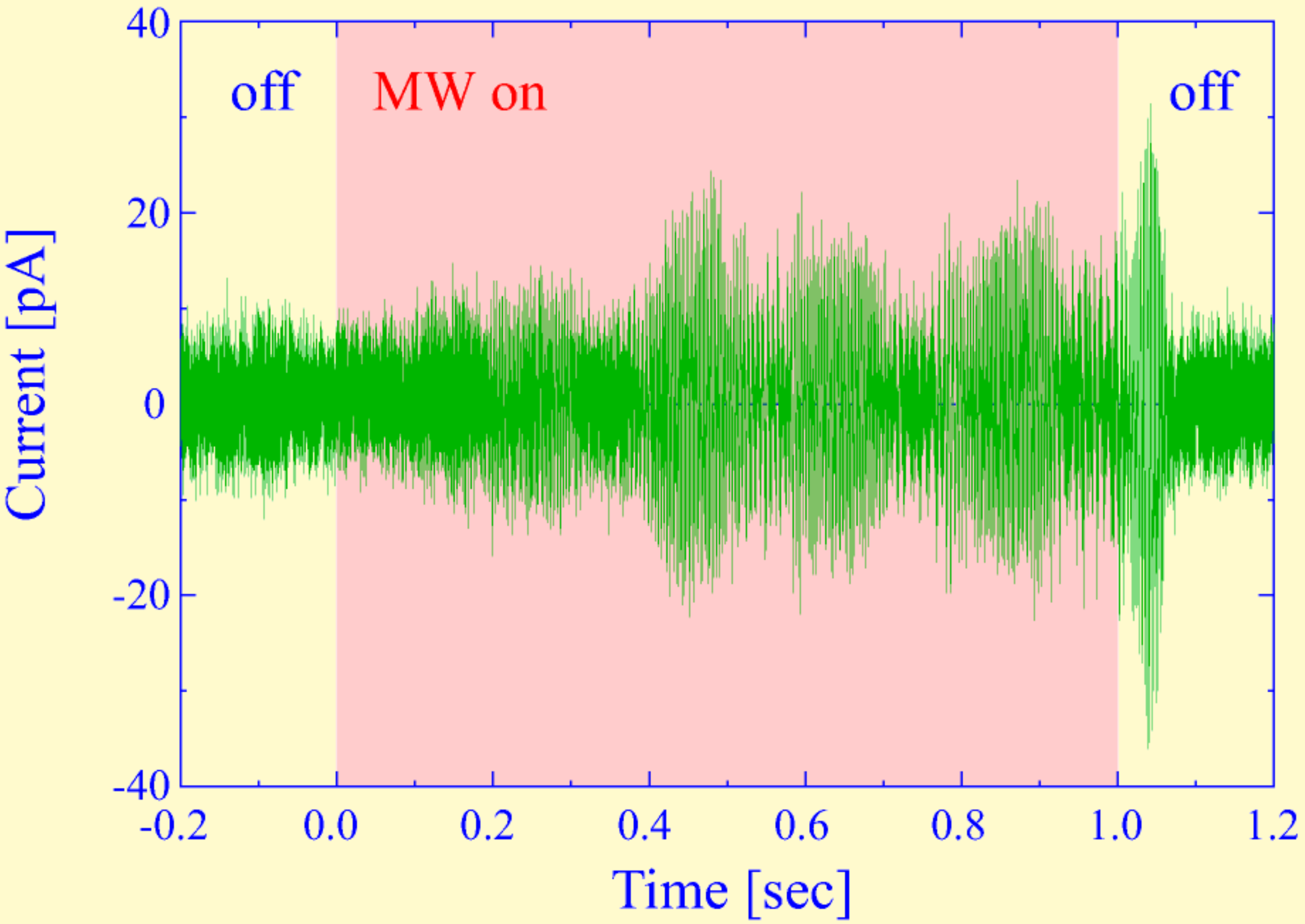
J. Phys. Soc. Jpn. 81 093601 (2012)



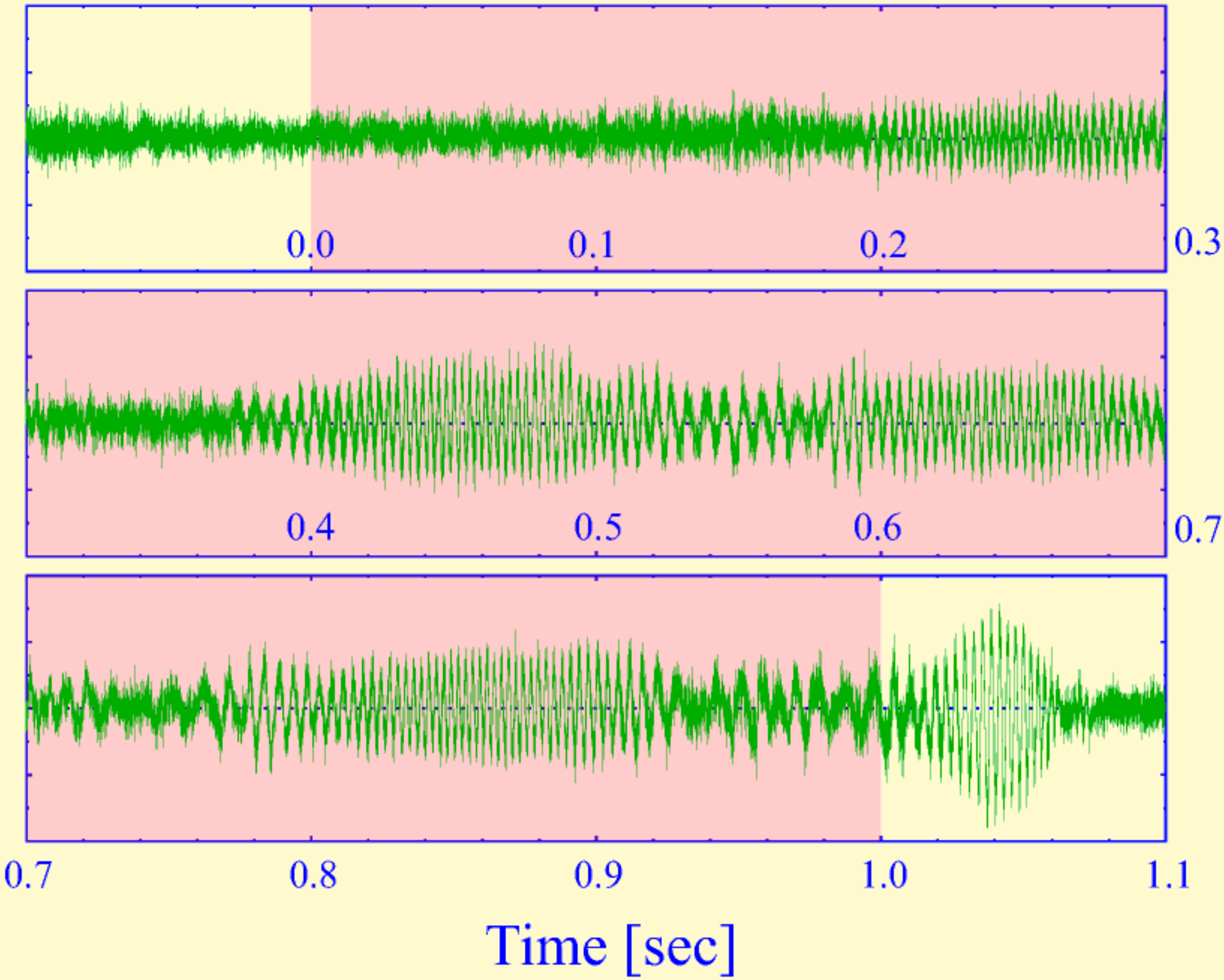
Displacement current vs. ZRS.



MW induced current oscillation

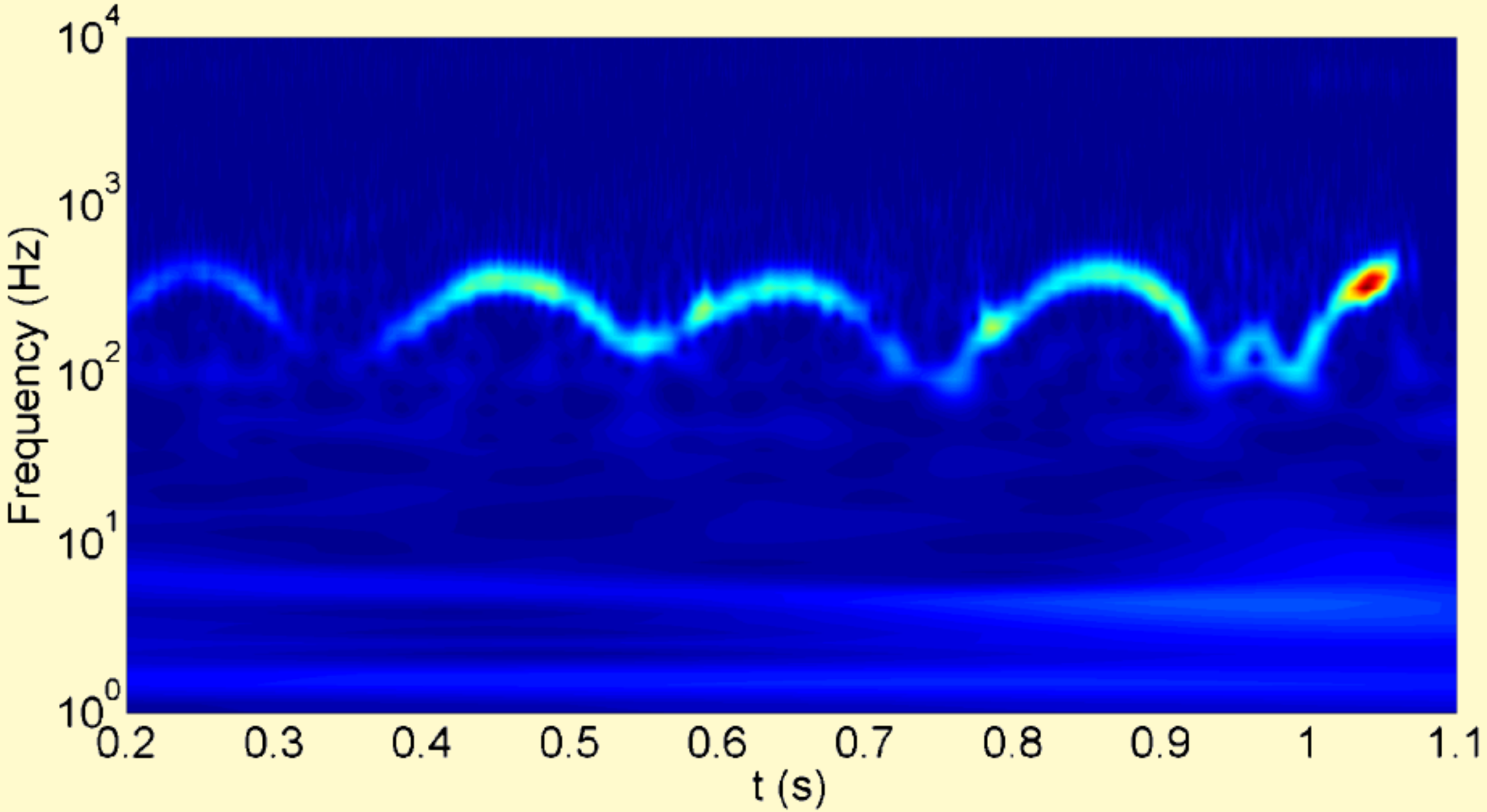


MW induced current oscilation (expanded)



Spectrum of current oscillation

J. Phys. Soc. Jpn. 82 075002 (2013)



Summary

- MW absorption
  - hot-electron
  - frequency shift
  - hysteresis
  - temperature bistability
- Quantizing magnetic field with MW
  - conductivity oscillations
  - zero resistance states
  - magnetic field dependent MW absorption
  - absorption saturation (not bereaching)
  - photovoltaic effect
  - Spontaneous current oscillation