

Enhanced Localization in Landau-Quantized Systems Induced by Very Low Frequencies

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Abstract. Quantum Hall samples with Corbino geometry show an enhanced hysteresis of the I - V curves near the breakdown of the Quantum Hall effect at low AC frequencies. We explain this finding within a hot-electron model by an assumed reduction of the subcritical conductivity σ_{xx} (under non-equilibrium conditions) with frequency. In this study, we present measurements of σ_{xx} as a function of the frequency on various samples. The observed drop of the subcritical σ_{xx} with frequency is of the same order as predicted and proves therefore our model.

INTRODUCTION

A variety of experimental and theoretical investigations has been dedicated to the breakdown of the quantum Hall effect (QHE, for a review see [1]). Frequently, the breakdown is accompanied by a hysteresis in the I - V curves, i.e. the system behaves bistable. The bistability can be explained by a hot-electron model (HEM) [2].

In comparison to the DC case we observed recently an enhancement of the breakdown hysteresis on QH Corbino devices when applying low-frequency AC driving voltages [3,4]. Within the HEM, the growing hysteresis can be attributed to a reduced conductivity σ_{xx} [4]. If the reduction of σ_{xx} is due to a background contribution occurring in addition to thermal activation, mainly the upper limit of the hysteresis V_{\max} is increased. This prediction was verified by our experimental observation (increase of V_{\max} , almost unchanged values for V_{\min} [4]). In this study, we measured σ_{xx} as a function of the frequency. From temperature- and bias-voltage-dependent measurements, we tried to identify the background contribution to σ_{xx} . In conclusion, we could verify our model predictions of a drop of the non-equilibrium conductivity σ_{xx} with the frequency. The background conductivity at subcritical voltages shows a temperature dependence like the variable range

hopping (VRH) conductivity at temperatures below 1K.

EXPERIMENTAL DETAILS

We have patterned Corbino devices with an inner radius of $r_i = 100\mu\text{m}$ and different outer radii r_a of $150\mu\text{m}$, $200\mu\text{m}$ and $300\mu\text{m}$ on two GaAs/GaAlAs wafers (A and B) with electron densities n_s and Hall mobilities μ_H of $n_s = 2.7 \times 10^{11} \text{cm}^{-2}$, $\mu_H = 1.0 \times 10^5 \text{cm}^2/\text{Vs}$ (A) and $n_s = 4.8 \times 10^{11} \text{cm}^{-2}$, $\mu_H = 1.8 \times 10^5 \text{cm}^2/\text{Vs}$ (B). The measurements of σ_{xx} were performed at filling factor 2, temperatures of $70\text{mK} \leq T \leq 4.2\text{K}$, frequencies from DC to 10kHz and bias voltages of $-V_C \leq V_{SD} \leq +V_C$ (V_C - breakdown voltage).

RESULTS AND DISCUSSION

Figure 1 shows the evolution of the breakdown hysteresis with frequency. Already at low frequencies (some Hz), V_{\max} increases steeply towards a saturation value, while V_{\min} remains almost unchanged. By this, the hysteresis $V_{\max} - V_{\min}$ nearly doubles at frequencies from 0 (DC) to less than 20Hz for this sample (wafer A, $r_a - r_i = 100\mu\text{m}$). The inset shows the DC I - V curve.

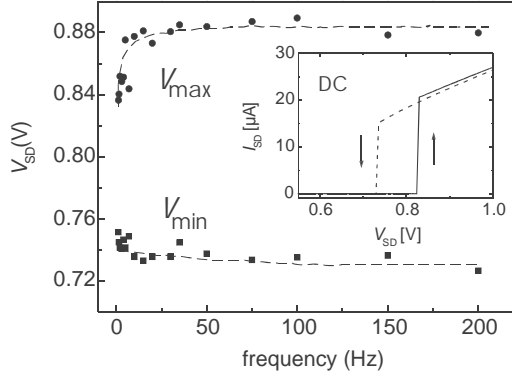


FIGURE 1. Hysteresis limits V_{\min} and V_{\max} vs. frequency. Inset: I - V curve at DC.

We explain the hysteresis observed by electron heating (HEM, see refs. [2,4]). If two contributions (thermal activated conductivity, σ_{TA} , and background conductivity, σ_{BG}) are assumed for σ_{xx} ($\sigma_{xx} = \sigma_{TA} + \sigma_{BG}$), the observed increase of V_{\max} is due to a decrease of σ_{BG} . This is shown in Figure 2, where a drop of σ_{BG} from $4.3 \times 10^{-8} S$ to $3.5 \times 10^{-8} S$ explains the increase of V_{\max} from 0.83V to 0.89V observed at low frequencies. The value of V_{\min} remains at 0.68V in the model (about 0.73V measured, for details see ref. [4]).

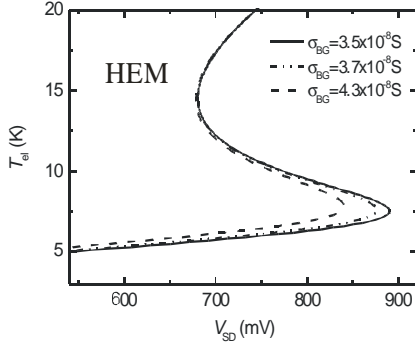


FIGURE 2. Breakdown hysteresis for various σ_{BG} (calculated with HEM, see text).

Thus, a drop of σ_{xx} of the order of $10^{-8} S$ is required to explain the observed increase of V_{\max} . We tested this prediction of the model by measurements of σ_{xx} as a function of the frequency. As shown in Fig. 3, we find a corresponding reduction of σ_{xx} in the same frequency range where the increase of V_{\max} was observed. The total value of σ_{xx} was measured at higher values than predicted, as a certain parallel conduction in the doping layer (decreasing with temperature) occurs. As σ_{xx} was measured at subcritical AC amplitudes, this indicates clearly that V_{\max} of the QHE breakdown is

determined by the subcritical behavior of σ_{xx} for our samples.

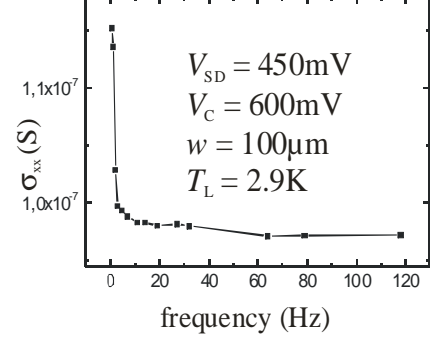


FIGURE 3. Subcritical conductivity σ_{xx} vs. frequency (measured values).

To understand the mechanisms which contribute to σ_{xx} , we performed voltage- and temperature-dependent AC measurements of σ_{xx} . At $T > 2K$, both Arrhenius- and VRH plots yield a good linearity, at $T < 1K$ the linearity of the VRH plot is better. However, there is not yet a theory for VRH at voltages as high as $V_{SD} \sim 0.5-0.8V_C$. Therefore, we can just qualitatively conclude that the breakdown delocalization is suppressed at AC in comparison to DC.

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