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 = 100µm and different outer radii r_a of 150µm, 200µm and 300µm on two GaAs/GaAlAs wafers (A and B) with electron densities n_s and Hall mobilities μ_H of $n_s = 2.7\times10^{11}$cm^{-2}, $\mu_H = 1.0\times10^5$cm^2/Vs (A) and $n_s = 4.8\times10^{11}$cm^{-2}, $\mu_H = 1.8\times10^5$cm^2/Vs (B). The measurements of σ_{xx} were performed at filling factor 2, temperatures of 70mK $\leq T \leq$ 4.2K, 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 = 100µm). The inset shows the DC *I-V* curve.

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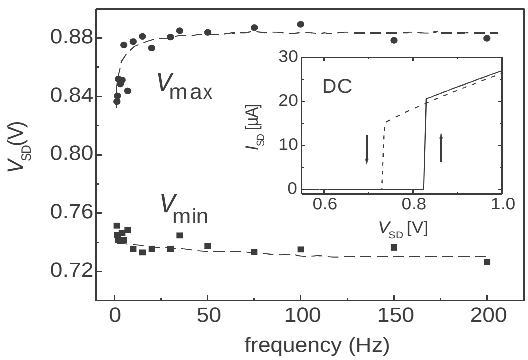

FIGURE 1. Hysteresis limits V_{min} and V_{max} vs. frequency. Inset: *I-V* curve at DC.

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 4.3×10^{-8}S to 3.5×10^{-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]).

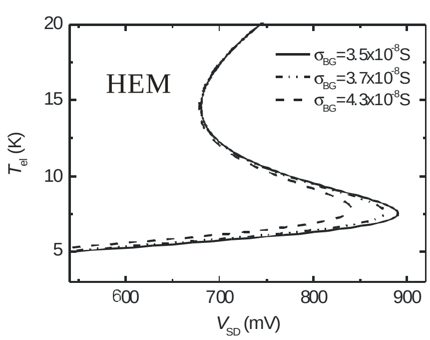

FIGURE 2. Breakdown hysteresis for various σ_{BG} (calculated with HEM, see text).

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.

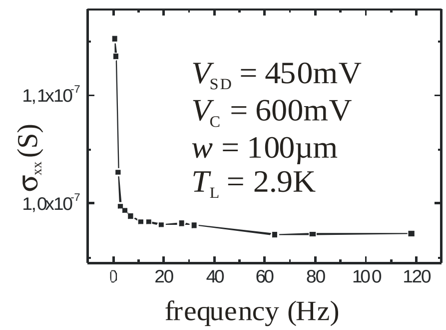

FIGURE 3. Subcritical conductivity σ_{xx} vs. frequency (measured values).

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} ~ 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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