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 ≤ T ≤ 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.

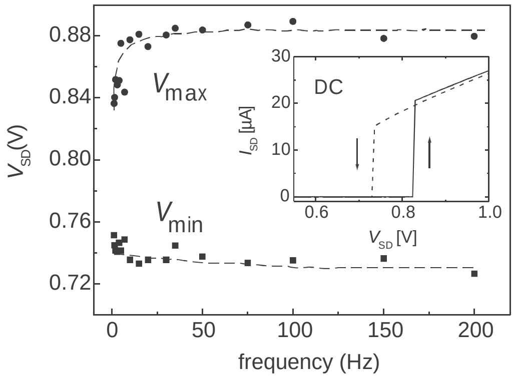

FIGURE 1. Hysteresis limits V_{min} and V_{max} vs. frequency. Inset: *I-V* curve at DC.

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]).

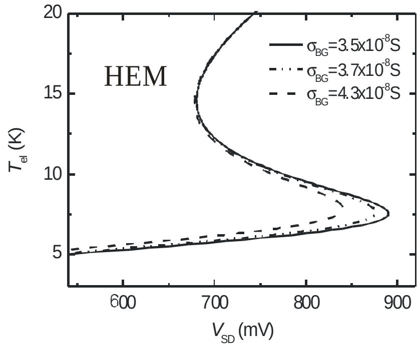

FIGURE 2. Breakdown hysteresis for various σ_{BG} (calculated with HEM, see text).

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.

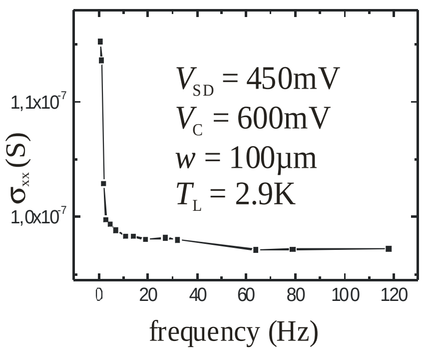

FIGURE 3. Subcritical conductivity σ_{xx} vs. frequency (measured values).

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.

ACKNOWLEDGEMENTS

This work was supported by the Deutsche Forschungsgemeinschaft. We thank Dr. N.G. Kalugin for suggesting the Corbino oscillator.

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