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(Article begins on next page)

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Measurement of excess noise of quantum Hall effect devices

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***Abstract*—Low-frequency excess noise is a sensitive probe of dissipation in quantum Hall effect (QHE) devices. We performed noise measurements on QHE devices hosted in a cryogen-free dilution refrigerator, with a two-channel correlation spectrum analyzer.**

Results on a metrology-grade epitaxial graphene QHE sample are reported. At zero or low magnetic field intensity the voltage spectra are dominated by flicker noise. Both flicker noise magnitude and the longitudinal resistance of the device are suppressed at quantization; their evolution as a function of the applied field shows similarity.

The activity demonstrates the feasibility of excess noise measurements on metrology-grade QHE samples in a dilution refrigerator environment in the low frequency range, 100 mHz to tens of Hz. The results support noise measurement as an investigation tool of QHE graphene devices, since the drop in measured flicker noise magnitude indicates the onset of quantization.

***Index Terms*—Graphene, noise measurement, electrical resistance measurement, metrology**

I. Introduction

Noise measurements probe microscopic charge-transport mechanisms and fluctuations that are not accessible in average conductance measurements, revealing information about disorder, coherence, and nonequilibrium effects.

In quantum Hall effect devices, the vanishing of low-frequency excess noise signals dissipationless transport and the onset of resistance quantization [1], [2], making noise a sensitive diagnostic of device quality and effects of magnetic field, temperature, and bias current magnitude on quantization.

We describe a correlation spectrum analyzer and its application to the measurement of low-frequency excess-noise spectra in quantum Hall effect (QHE) devices for metrological purposes in a dry cryostat environment. We present results from an investigation of an epitaxial graphene QHE device. The activity is ongoing; additional results and a detailed discussion of the underlying device physics will be presented at the Conference.

II. Measurement setup

A simplified schematic diagram of the experiment is shown in Figure 1. The QHE device in the cryogenic environment is connected to room temperature electronics. A low-noise source generates the dc measurement current I; two differential voltage amplifiers A1 and A2 are connected to the QHE device terminals and measure voltages V_1 and V_2. The outputs of A1 and A2 are sampled by two analog-to-digital converters ADC1, ADC2; the time series are saved for off-line processing, which includes estimation of the power spectral densities (PSDs) $S_{11}(f)$ and $S_{22}(f)$, and the cross power spectral density (CSD) $S_{12}(f)$, of V_1 and V_2.

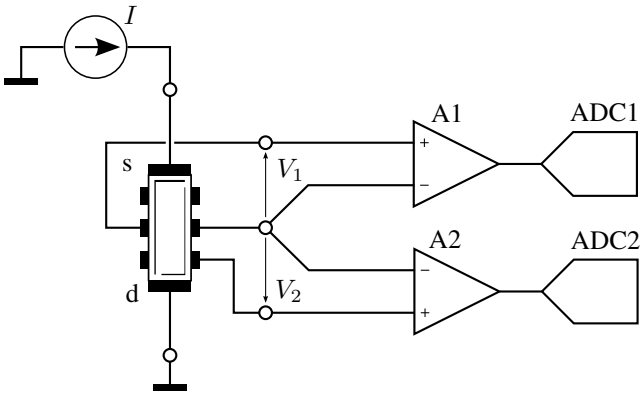

Fig. 1. Simplified schematic diagram of the noise measurement setup, described in Sec. II. The two differential inputs of the amplifiers A1 and A2 can be connected to any terminal pairs of the QHE devices. In the specific connection shown, the setup samples the Hall voltage V_{H} with channel 1 and the longitudinal voltage V_{xx} with channel 2.

The inputs of A1 and A2 can be connected either to the same QHE terminal pairs (voltage or current), or different ones. When connected to the same terminal couple the cross-correlation method allows to reject the amplifiers' noise [3]. If connected to different terminals, it is possible to determine the correlation between two different noise voltages occurring on the QHE device.

The experiment is performed in a cryogen-free dilution refrigerator (CF-CS110, Leiden Cryogenics) with a 9 T superconducting magnet. It includes five temperature stages, nominally established at 50 K, 3 K, 0.7 K, 50 mK, and 10 mK.

The correlation spectrum analyzer is an evolution of that described in [3]. A1 and A2 are two FET differential amplifier modules (Stanford Research System SIM910, 4 nV Hz$^{-1/2}$ voltage noise, 0.5 pA bias current) in AC coupling mode (low-frequency cutoff 16 mHz). ADC1 and ADC2 are the channels of an ADC board (National Instruments 4462, 24 bit resolution, 204.8 kHz maximum sampling frequency, 300 mV input full scale).

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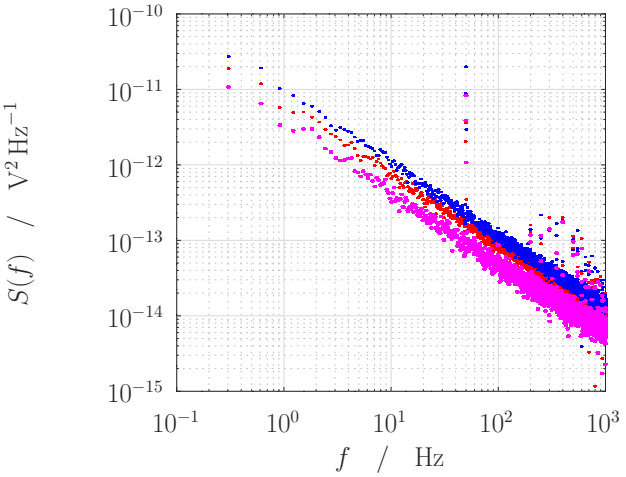

Fig. 2. An example of measurement outcome. Sample G52, $B = 0.7\,\mathrm{T}$, $T = 3.6\,\mathrm{K}$, $I = 10\,\mu\mathrm{A}$. (•) $S_{V_\mathrm{H}}(f)$, (•) $S_{V_\mathrm{xx}}(f)$, (•) $S_{V_\mathrm{H},V_\mathrm{xx}}(f)$.

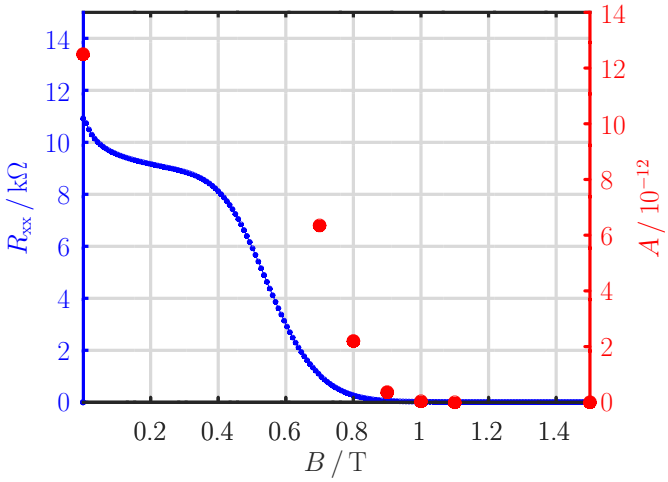

Fig. 3. (•) Flicker noise magnitude A_{V_H} and (•) longitudinal resistance R_xx versus the applied magnetic field B, see also Figure 2 and Sec. IV.

III. Devices

Both GaAs and graphene QHE devices have been investigated. In this summary the measurement results on the QHE device G52 are reported. G52 is a QHE device based on molecularly doped (F4-TCNQ) monolayer epitaxial graphene grown on a SiC substrate and mounted on a TO-8 chip carrier, qualified for the realisation of the SI ohm under relaxed experimental conditions [4].

IV. Results

Figure 2 shows a typical outcome of a measurement. The sample is at temperature $T = 3.6\,\mathrm{K}$ (dilution stage is not operational), with an applied magnetic field $B = 0.7\,\mathrm{T}$, with a bias current $I = 10\,\mu\mathrm{A}$. A1 is connected to V_H, A2 to V_xx.

The PSDs $S_{V_\mathrm{H}}(f)$ and $S_{V_\mathrm{xx}}(f)$ of V_H and V_xx, and the CSD $S_{V_\mathrm{H},V_\mathrm{xx}}(f)$ are plotted. Since B is well below the quantization threshold, the flicker noise dominates.

In the audio frequency range the spectra are perturbed by interferences caused by pickup from the mains and by electromechanical coupling to the dry cryostat vibrations. Nevertheless, below about 40 Hz the spectra are unperturbed, and the magnitude A and slope α parameters of the flicker noise, modeled as $S(f) = Af^{-\alpha}$, can be successfully determined by least-squares fitting.

All spectra have α in the 0.9 to 1.1 range. V_xx and V_H have a magnitude-squared coherence of about 0.22, with a large V_xx noise magnitude. This suggests a role of mobility fluctuations in the noise generation mechanism, already observed at room temperature on mechanically exfoliated graphene [5], and deserves further investigation.

Figure 3 shows the flicker noise magnitude A_{V_H} versus B, and compares it with the longitudinal resistance R_xx, the latter being the standard indicator of the approach to quantization. The evolutions of the two quantities versus B show similarities, although the different B values for which two curves drop to negligible values are different.

V. Outlook

This summary provides evidence of the technical feasibility of noise measurement on QHE samples in a dry dilution refrigerator environment at low frequency, down to the 100 mHz range. The relationship between the quantization status and the flicker noise magnitude, already observed in the past for the magnetoresistance current noise [2], is qualitatively confirmed when the Hall V_H voltage noise is considered.

The cross-correlation technique allows to investigate and improve the understanding of the noise mechanisms at the onset of quantization. More results, an improved quantification of the effects observed, and possible interpretation will be provided at the Conference.

Acknowledgments

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References

[1] J. Schurr, F. Ahlers, and L. Callegaro, "Noise and correlation study of quantum Hall devices," *IEEE Trans. Instrum. Meas.*, vol. 62, no. 6, pp. 1574–1580, 2013.

[2] C.-C. Kalmbach, F. J. Ahlers, J. Schurr, A. Müller, J. Feilhauer, M. Kruskopf, K. Pierz, F. Hohls, and R. J. Haug, "Nonequilibrium mesoscopic conductance fluctuations as the origin of $1/f$ noise in epitaxial graphene," *Phys. Rev. B*, vol. 94, no. 20, p. 205430, 2016.

[3] M. Marzano, A. Cultrera, M. Ortolano, and L. Callegaro, "A correlation noise spectrometer for flicker noise measurement in graphene samples," *Meas. Sci. Technol.*, vol. 30, no. 3, p. 035102, 2019.

[4] Y. Yin, M. Kruskopf, P. Gournay, B. Rolland, M. Götz, E. Pesel, T. Tschirner, D. Momeni, A. Chatterjee, F. Hohls, K. Pierz, H. Scherer, R. J. Haug, and H. W. Schumacher, "Graphene quantum Hall resistance standard for realizing the unit of electrical resistance under relaxed experimental conditions," *Phys. Rev. Appl.*, vol. 23, no. 1, p. 014025, 2025.

[5] A. Rehman, J. A. Delgado Notario, J. Salvador Sanchez, Y. M. Meziani, G. Cywiński, W. Knap, A. A. Balandin, M. Levinshtein, and S. Rumyantsev, "Nature of the $1/f$ noise in graphene: direct evidence for the mobility fluctuation mechanism," *Nanoscale*, vol. 14, no. 19, pp. 7242–7249, 2022.