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Comparison of 1 MΩ Graphene Quantum Hall Arrays Based on Wye-Delta Transformation

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***Abstract* — Utilization of the wye-delta transformation significantly reduces the number of Hall bars in quantum Hall array devices for high resistances above 1 MΩ, improving the yield of fabrication. We fabricated two types of wye-delta quantum Hall array devices that produce near 1 MΩ resistance, each consisting of 28 and 18 Hall bars, respectively. In this work, we report the measurement results of the 28-element quantum Hall arrays using a dual-source bridge (DSB) and two 1 MΩ standard resistors. This indirect comparison shows that two identical arrays are quantized at 77 $\frac{h}{2e^2}$ (≈1 MΩ) to within 60 nΩ/Ω at magnetic fields of 5 T and 6 T. We will use the DSB to perform the direct comparison of two 18-element arrays without the 1 MΩ standard resistors in the coming months.**

***Index Terms* — dual-source bridge (DSB), wye-delta transformation, quantum Hall array.**

I. Introduction

The wye-delta (Y-Δ) transformation [1] is a common technique used to generate ultra-high resistance standard in the range of MΩ to PΩ [2, 3] and is currently being investigated as an alternative technique to generate quantum Hall array resistance standards (QHARS) with fewer Hall elements than traditional series QHARS [4, 5]. This technique attests the equivalence of a "Y"-shaped network and a "Δ"-shaped that connect three terminals A, B, and C [5]. Figure 1(a) shows the diagram of a quantum Hall array (QHA) device with a Y-network formed by three resistors R_1, R_2 and R_3, where two series arrays of n_1 and n_2 Hall bars are implemented for R_1 and R_2, respectively, and R_3 is single Hall bar. Ideally, each Hall bar manifests a robust resistance of $R_H = h/(2e^2)$ in the quantized state for metrology application, where h is the Planck constant and e is the elementary charge.

The equivalent resistance R_C in the corresponding Δ-network, between the nodes A and B, is calculated by equation (1).

$$R_C = R_1 + R_2 + \frac{R_1 R_2}{R_3} = (n_1 + n_2 + n_1 n_2)\frac{h}{2e^2} \quad (1)$$

Based on Fig. 1, there are two configurations, $(n_1, n_2, n_3) = (12,5,1)$ and $(n_1, n_2, n_3) = (25,2,1)$, that produce $R_C = 77\frac{h}{2e^2} \approx 1$ MΩ, requiring only 18 and 28 Hall bars, respectively, while a pure series array requires 77 Hall bars.

This work will present two approaches, the indirect comparison and the direct comparison, to measure the 1 MΩ graphene-based QHA devices with the configuration (12,5,1) and (25,2,1). Our samples are fabricated following the previous methods, using a metal protection layer to prevent contamination during the fabrication [6] and superconducting interconnections between the Hall bars in the Y-network [7].

II. Experiments

Indirect Comparison

We applied the indirect comparison for three (25,2,1) devices (B8, B9 and B11) using a DSB and two NIST (National Institute of Standards and Technology) 1 MΩ standard resistors R6 and R7.

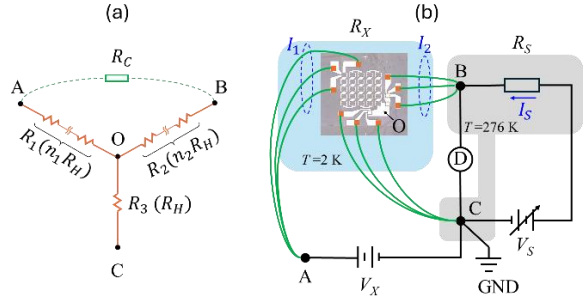


Fig. 1. (a) Diagram for QHARS based on Y-Δ transformation. (b) Diagram of the DSB measurement of QHA device with Y-network (25,2,1).

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Figure 1b shows the diagram of the DSB measurement setup, which comprises two programmable voltage sources and a nanovoltmeter. Triple connections are made to nodes A, B, and C to reduce the effect of the leads and contact resistance [8]. Under the balance condition when the detector voltage $V_D = 0$, the ratio of the output voltages of the calibrators ($V_X = V_{X0}$, $V_S = V_{S0}$), is equal to the ratio of the resistance values, $V_{X0}/V_{S0} = R_X/R_S$. The measured value of $R_X = \frac{V_X}{V_S} R_S = \frac{V_X}{I_S}$ is the equivalent resistance R_C of the QHA device.

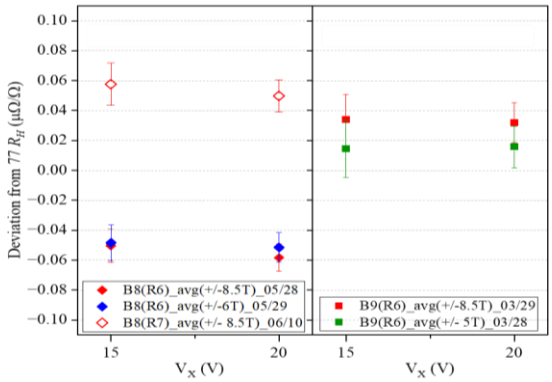


Fig. 2. DSB measurements of B8 (left panel) and B9 (right panel) at T = 2 K. The error bars are type-A uncertainty of the measurements.

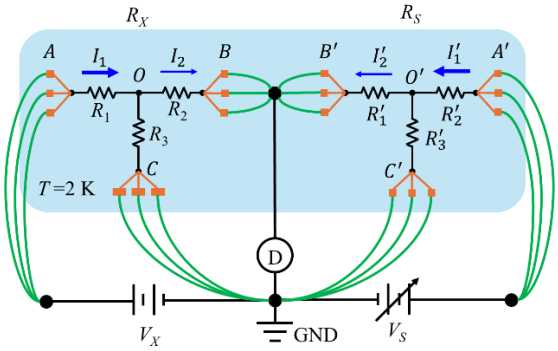


Fig. 3. Diagram of the DSB for direct comparison of two graphene QHA devices with (12,5,1) Y-network.

Figure 2 shows the DSB measurements of devices B8 and B9 at 15 V and 20 V. At 2 K, B8 is quantized to within 60 nΩ/Ω in the magnetic fields of 6 T and 8.5 T (left panel). The solid diamond data sets, B8(R6), are obtained with R6 as the standard, where the hollow diamond data set, B8(R7), is obtained with R7 as the standard. Similarly, device B9 is quantized to within 40 nΩ/Ω in the magnetic fields of 5 T and 8.5 T (right panel), measured against R6.

The data presented in Fig. 2 have been processed by a substitution method using corresponding measurements of R7(R6) or R6(R7) as the reference data set. Each data point is the average of the measurements in two opposite magnetic field directions. In the conference, we will present the details of the substitution method and a thorough analysis of the uncertainty budget, including the instability of the calibrator, the uncertainty associated with different output ranges of the calibrators, and the instability of the standard resistors R6 and R7.

Direct Comparison

To eliminate the uncertainty due to the instability of the 1 MΩ stadard resistors, we will replace the *R*s in Fig. 1b with another 1 MΩ QHA device. We have fabricated multiple (12,5,1) QHA devices and designed a sample stage to hold two TO-8 headers in a liquid helium cryostat. As shown in Fig. 3, this measurement will compare two 1 MΩ QHA devices directly.

III. Conclusion

We fabricated two types of wye-delta type QHA devices with nominal resistance of $77\frac{h}{2e^2}$ (≈1 MΩ). The fabrication yield is improved due to the reduced number of graphene Hall bars in the wye-delta arrays. The indirect comparison shows that two (25,2,1) arrays are quantized to within 60 nΩ/Ω at magnetic field as low as 5 T. We will perform the direct comparison of (12,5,1) arrays in the coming months.

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