Graphene quantum Hall resistance standard for realizing the unit of resistance under relaxed experimental conditions

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The quantum Hall effect is the basis for defining the unit of electrical resistance, the ohm, in the revised International System of Units (SI). [1] The practical realization of the ohm is carried out using a quantum Hall resistance standard (QHRS) with the exact value $R_{\mathrm{H}} = h/2e^2$ (filling factor $\nu = 2$). Other SI units such as the farad, the ampere, and the kilogram (Kibble balance), which all require the realization of the ohm in their traceability route to the SI, also rely on the QHRS. [1] Therefore, the QHRS play an essential role in the implementation of the new SI. Conventional QHRS is based on GaAs heterostructures. In the past decade, epitaxial graphene on SiC has emerged as a new material for QHRS, instead of GaAs. [2-5] Due to its wide gap between the Landau levels and strong pinning of the Fermi level, the epitaxial graphene allows for the realization of the SI unit of resistance under relaxed experimental conditions in terms of magnetic field *B,* current *I* and temperature *T*. It bears a great potential to substitute GaAs-based heterostructures as QHRS in the future. However, realizing the QHRS with high accuracy under those relaxed conditions is challenging, due to the mutual constraint of *B*, *I*, and *T* on the quantum Hall effect.

Here we present epitaxial graphene-based QHRS which allow for the realization of the SI ohm with an accuracy of nΩ/Ω level at a low magnetic field of $B = 4.5$ T, a high current of $I = 232.5$ μA, and a temperature of $T = 4.2$ K simultaneously, as shown in Fig.1. To the best of our knowledge, this is the best performance of graphene-based QHRS obtained under (*B*, *I*, *T*) relaxed experimental conditions. Repeated high-precision measurements also demonstrate that the quantized resistance has remained stable within an accuracy of nΩ/Ω over a period of 2.5 years, so far. Furthermore, the accuracy of the graphene-based QHRS has been maintained without any signs of degradation, even after experiencing a long-distance transport between PTB and BIPM. It is expected that the superior performance of graphene QHRS may lead to a broader dissemination and proliferation of primary quantum standards, not only in national metrology institutes but also beyond in calibration laboratories and industry.

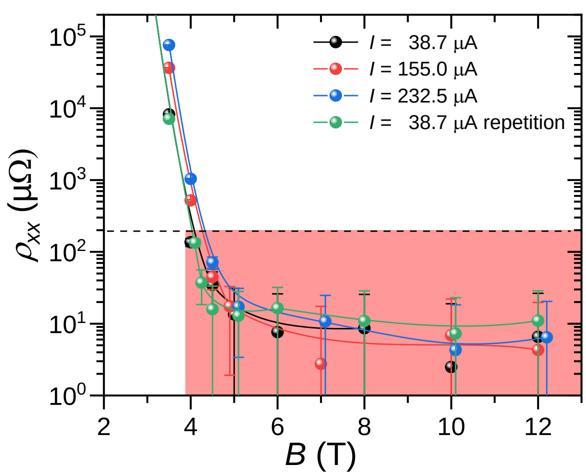

Fig. 1. The longitudinal resistivity as a function of the magnetic field measured at the following currents (I = 38.7, 155.0, and 232.5 μA) and again at 38.7 μA for a graphene-based QHR standard at 4.2 K. The dashed line corresponds to $\rho_{xx} = 200$ μΩ below which, the relative deviation of R_{xy} from $R_K/2$ remains less than 2 nΩ/Ω. The error bars represent the combined standard uncertainty ($k = 2$).

References

[1] SI Brochure Appendix 2, 9th edition, 2019, https://www.bipm.org/en/publications/mises-en-pratique

[2] A. Tzalenchuk, et al., Nat. Nanotechnol. **5**, 186 (2010).

[3] R. Ribeiro-Palau, et al., Nat. Nanotechnol. **10**, 965 (2015).

[4] H. He, et al., Metrologia **56**, 045004 (2019).

[5] Y. Yin, et al., Adv. Phys. Res. **1**, 2200015 (2022).