

Graphene-based Hall devices for electrical quantum resistance metrology

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DC and Quantum Metrology Meeting 2021

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Outline

Introduction

- Motivation and goal
- Development history at PTB
- Charge carrier density control, device stability
 - Photochemical gating
 - **F4-TCNQ molecular doping**
- dc QHR precision measurements

Introduction: Graphene quantum resistance standards

- Motivation: Graphene-based quantized Hall resistance (QHR) devices allow the realization of the unit "Ohm" under relaxed measurement conditions:
 - Lower requirements compared to former GaAsbased standards.
 - Wide resistance plateaus starting at a few Tesla
 - Higher measurement temperature ~ 4.2 K



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Graphene:

Ribeiro-Palau *et al.* (2015), *Nature Nanot*. DOI: 10.1038/nnano.2015.192 Kruskopf *et al.* (2018), *Metrologia*, DOI: 10.1088/1681-7575/aacd23

GaAs-based:

Pierz et al. (2011), IEEE Trans. Instr. Meas., DOI: 10.1109/TIM.2010.2100651 Kučera et al. (2019), IEEE Trans. Instr. Meas., DOI: 10.1109/TIM.2018.2882216

Introduction: Graphene quantum resistance standards

 Goal: Compact and easy-to-use QHR systems based on closed cycle cryostats for AC and DC resistance metrology.



compact closed cycle cryostat at PTB, 2.6





Cryogenic Current Comparator (CCC) System from Magnicon, developed at PTB

Device characteristics - Development history at PTB



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Charge carrier density control, device stability: photo-chemical gating

Problems with photo-chemical gating:

- The resist layer tends to crack after one cooldown / warmup cycle
- The charge carrier density is not stable over several months.

hair line cracks!





graphene Hall bar under the microscope after cooldown, PTB 2015

Lara-Avila et al. (2011), *Advanced Materials*, DOI: 10.1002/adma.201003993

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Charge carrier density control, device stability: F4-TCNQ molecular doping

F4-TCNQ doping:

- graphene device is cleaned/preconditioned by pre-annealing
- The charge carrier density can be controlled by the F4-TCNQ concentration in the dopant blend.



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Yefei Yin et al., (unpublished), *Phd work at PTB*

H2 pre-annealing Vacuum pre-annealing

Charge carrier density control, device stability: <u>F4-TCNQ molecular doping</u>

Stability of charge carrier density (F4-TCNQ doping):

- Reusable & high stability over time even during shipping
- Stability is best when device is stored in an inert gas container







National Metrology Institute

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DC QHR precision measurements

CCC QHR measurements:

- QHR with 1 ppb precision starts at B = 3.5 T
- Ideal for table-top closed cycle cryostats





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- F4-TCNQ doped graphene QHR devices are well suited for applications in quantum resistance metrology.
 - Devices are sufficiently stable over several cooldown cycles
 - Shipping for international interlaboratory comparison successfully tested
 - Resistance quantization with 1 ppb precision starts at B = 3.5 T and T = 4.2 K
- At the PTB, the transition from GaAs-based to graphenebased QHR devices for dc resistance calibrations started this year.



Thank you!



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