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Design and development of a coaxial cryogenic probe for precision measurements of the quantum Hall effect in the AC regime

Original

Design and development of a coaxial cryogenic probe for precision measurements of the quantum Hall effect in the AC regime / Marzano, Martina; Tran, Ngoc Thanh Mai; D'Elia, Vincenzo; Serazio, Danilo; Enrico, Emanuele; Ortolano, Massimo; Pierz, Klaus; Kucera, Jan; Callegaro, Luca. - In: ACTA IMEKO. - ISSN 2221-870X. - 10:2(2021), p. 24. [10.21014/acta_imeko.v10i2.925]

Availability:

This version is available at: 11696/73322 since: 2022-02-21T09:54:35Z

Publisher:

Imeko

Published

DOI:10.21014/acta_imeko.v10i2.925

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Figure 1. A computer rendering of the cryomagnetic probe assembly: (left) side view; (right) front view, showing the magnet bore.

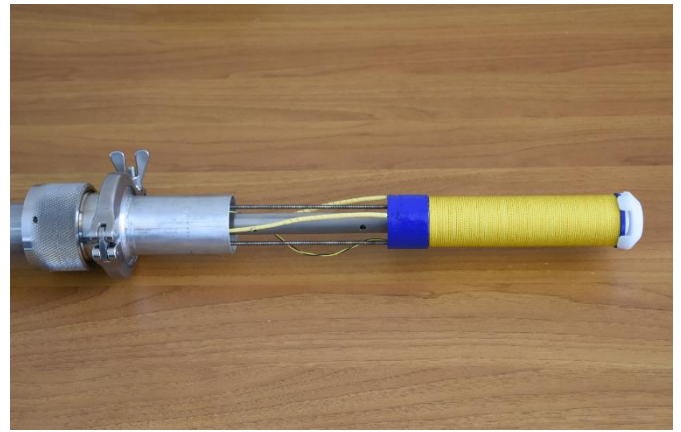


Figure 2. The probe cryomagnet, showing the yellow winding insulation. A header (white) was added to ease the insertion in the cryostat.

The cryomagnetic probe assembly is designed for high-resolution NMR spectroscopy. It consists of a long, thin probe body and a separate cryomagnet component. The probe body is made of stainless steel and has a blue section at the bottom. The cryomagnet is made of aluminum and has a yellow winding insulation on the right side and a white header at the left end. The probe is used to measure the magnetic field of the sample and the resulting NMR signal. The cryomagnet is used to cool the probe and the sample to the required temperature. The white header is used to ease the insertion of the probe into the cryostat.

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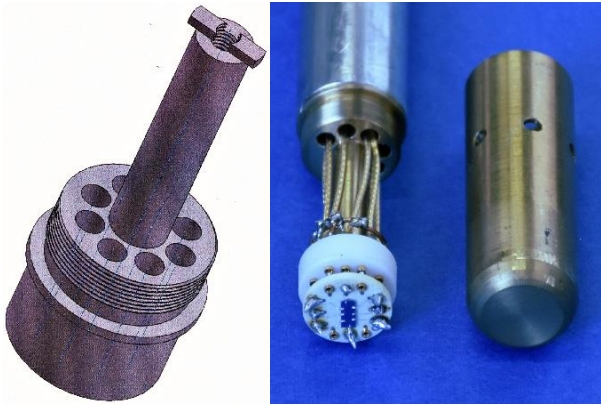


Figure 3. The bottom side of the insert, which slides into the cryomagnet bore. (left) Diagram of the drum that supports the sample holder and hosts the 9 coaxial connections. (right) Photo of the assembled probe: the brass shield (right) has been removed to show the TO-8 socket, which hosts a GaAs device on its TO-8 holder, and the 9 coaxial electrical lines.

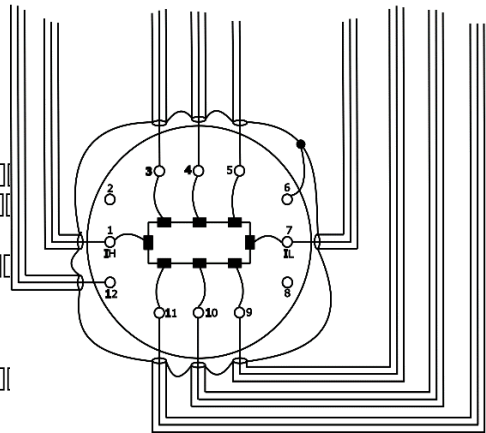
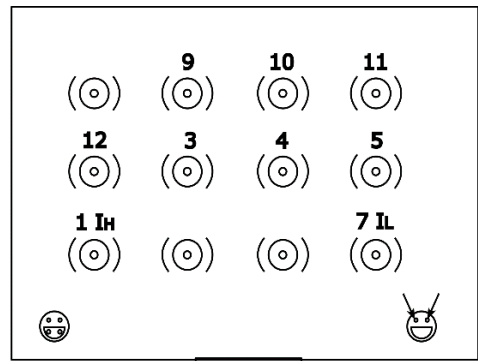


Figure 5. Schematic diagram of the coaxial connections of the probe. Nine coaxial connections are available, fully isolated from the probe metal bulk. The outer conductors of each line are joined together on the sample holder (Table 6).

UHV L V W D Q F H R I D E R X W P

B n h e

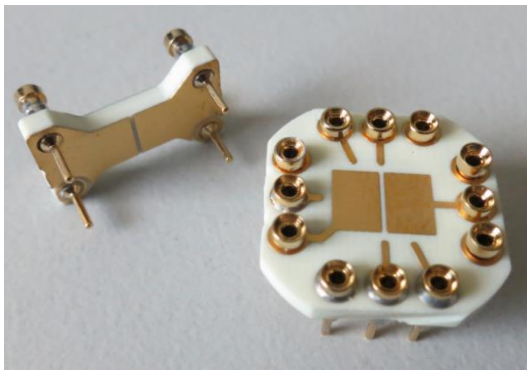


Figure 4. TO-8 sample holders, implementing the double-shielding technique [8], [17]. After the bonding of the quantum Hall device onto the holder (right), the shielding cap (left) slides into the socket.

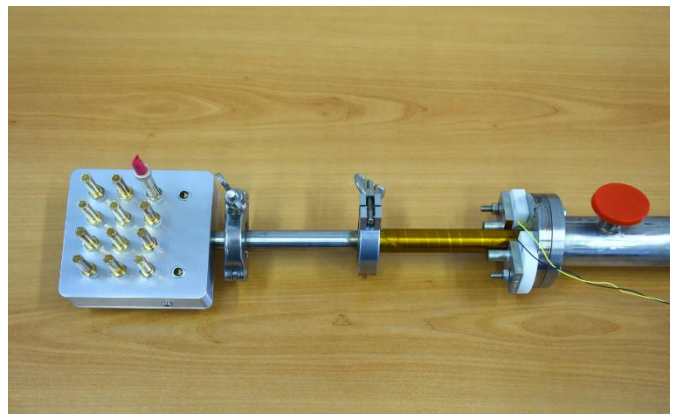


Figure 6. The probe connection box.

The overall view of the measurement setup for DC characterization. On the left, the liquid helium dewar, with the coaxial probe inserted. On the right, the rack of electronic instrumentation.



Figure 7. Overall view of the measurement setup for DC characterization. On the left, the liquid helium dewar, with the coaxial probe inserted. On the right, the rack of electronic instrumentation.

The measured values of R_H and R_{xx} versus the magnetic field B , for an applied current $I = 20 \mu A$. Blue line: increasing magnetic field. Red line: decreasing magnetic field.

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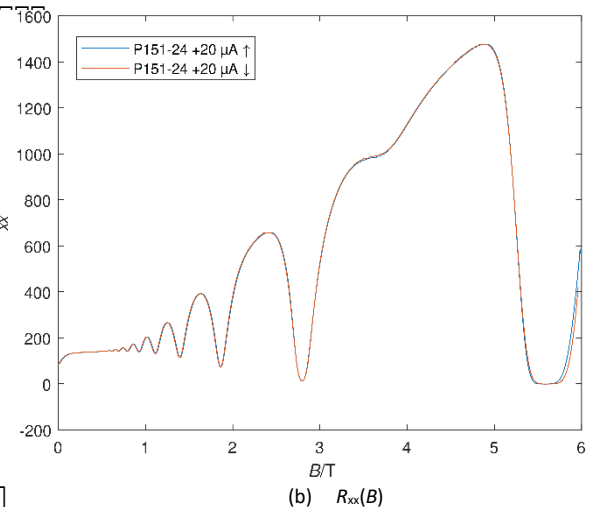
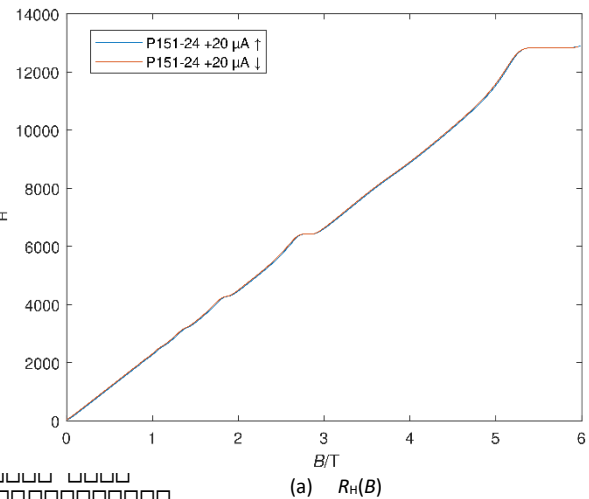


Figure 8. Plot of the measured values of R_H and R_{xx} versus the magnetic field B , for an applied current $I = 20 \mu A$. Blue line: increasing magnetic field. Red line: decreasing magnetic field.

Table 1. Calculation of the real part of the relative error δZ_H occurring when measuring a QHE device by using the n -series connections given in Figure 9, for the frequency $f = 1541$ Hz. The calculation is given for two different contact resistance values.

δZ	n	$R = 10 \text{ m}\Omega$	$R = 10 \Omega$
	1	$+1.0 \times 10^{-4}$	$+1.7 \times 10^{-3}$
	2	-5.6×10^{-9}	$+1.4 \times 10^{-6}$
	3	-1.1×10^{-8}	-9.5×10^{-9}

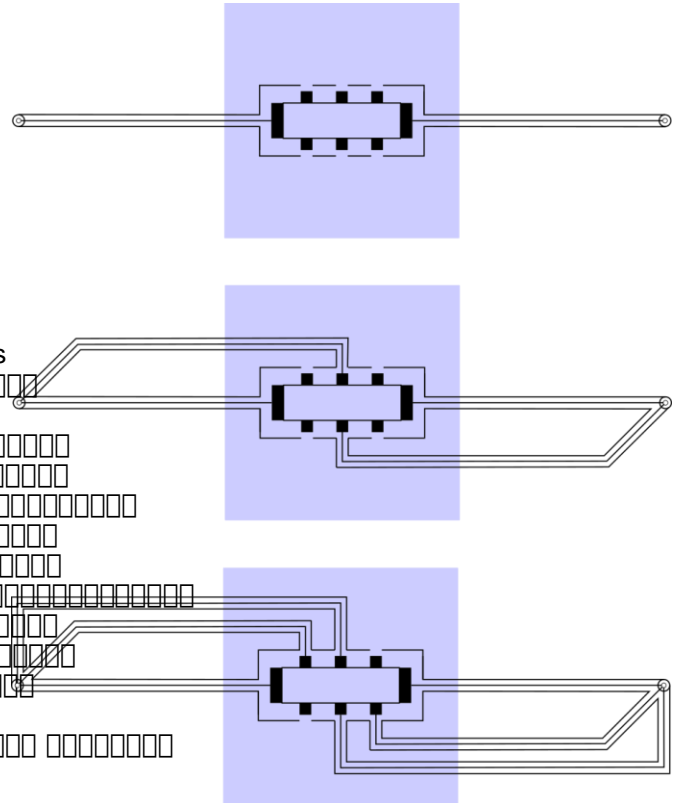
Double series triple series

Z_H is the Hall impedance of the device. R_H is the Hall resistance. Z_w is the series impedance of the connection. Y_w is the parallel admittance of the connection. R_c is the contact resistance. R_U is the resistance of the voltmeter. R_I is the resistance of the current source. P is the power. D is the diameter. Q is the charge. G is the conductance.

$$\delta Z_H = \frac{Z_H - R_H}{R_H}$$

III

Figure 9. n -series connection of a QHE device. (top) $n = 1$, no multiple-series connection: the device is connected as a 2TP impedance by two coaxial leads. (middle) $n = 2$, double-series connection. (low) $n = 3$, triple-series connection.



Z_H is the Hall impedance of the device. R_H is the Hall resistance. Z_w is the series impedance of the connection. Y_w is the parallel admittance of the connection. R_c is the contact resistance. R_U is the resistance of the voltmeter. R_I is the resistance of the current source. P is the power. D is the diameter. Q is the charge. G is the conductance.

$$\delta Z_H \approx \left[\frac{Z_w Y_w}{2} + \left(\frac{R_c + R_w}{R_H} \right)^n \right]^2$$

III

R_U is the resistance of the voltmeter. R_I is the resistance of the current source. P is the power. D is the diameter. Q is the charge. G is the conductance.

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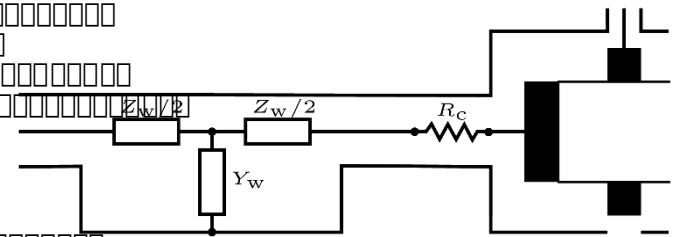


Figure 10 Electrical modelling of one of the connections to the QHE device. In the AC regime, each connection is modelled as a T network with series impedance Z_w and a parallel admittance Y_w . The contact resistance R_c models the bonding and the device junctions.

GIQS: Graphene Impedance Quantum Standard

Abstract: This paper introduces the Graphene Impedance Quantum Standard (GIQS), a novel quantum standard for impedance measurement. It is based on the quantum Hall effect in graphene, providing a highly accurate and stable reference for impedance calibration. The standard is designed to be compatible with existing measurement systems and is expected to revolutionize the field of impedance metrology.

1. Introduction: Impedance is a fundamental property of electrical circuits, and its accurate measurement is crucial for many applications. However, traditional impedance standards are often limited in accuracy and stability. The GIQS offers a quantum-based solution, leveraging the unique properties of graphene to achieve unprecedented precision.

2. Theory: The GIQS is based on the quantum Hall effect in graphene, where the Hall resistance is quantized in units of $\frac{h}{4e^2}$. This quantization is highly stable and insensitive to external factors, making it an ideal candidate for a quantum standard.

3. Experimental Setup: The GIQS is implemented using a high-quality graphene device. The device is connected to a four-terminal measurement setup, and the Hall resistance is measured under a magnetic field. The setup is designed to minimize parasitic effects and ensure accurate measurements.

4. Results: The GIQS has been characterized and compared to traditional standards. The results show that the GIQS provides a significantly higher accuracy and stability than conventional standards, particularly at high frequencies and in complex environments.

5. Conclusion: The GIQS represents a major advancement in impedance metrology. It offers a quantum-based standard that is highly accurate, stable, and easy to use. This standard is expected to be widely adopted in the future, leading to more precise and reliable impedance measurements.

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