HIGHLIGHTS OF ELECTRICAL METROLOGY 2013 – 2014

MIKES

Graphene

A set of graphene QHE devices, fabricated in Aalto University, were investigated in MIKES and suitable devices for accurate resistance measurements were chosen. Non-homogeneity of carrier density distribution and variation in carrier mobility at different areas of the devices were the main factors limiting the precision measurements. Adjustment of the carrier density to the optimum values using photochemical and chemical functionalization of graphene allowed observation of half-integer quantum Hall effect with $v = 2$ plateau starting at relatively low (3 T) magnetic field. Accurate measurements of a 100 Ω resistance standard against $R_H(2)$ on graphene QHR device (at B = 7 T, T = 1.5 K, and I_{sd}=33 µA) and on GaAs device, performed with CCC bridge, showed an agreement within (6-10)·10^{-9} Ω/Ω [1,2].

JRP ENV01 MACPoll ended in June 2014. MIKES, in collaboration with Aalto developed graphene-based sensors for ultra-sensitive NO_2 and O_3 detection [3].

In JRP SIB51 GraphOhm, two prototypes of a current comparator for operation at low frequencies (LFCC) and at room temperature have been realized in MIKES. The measured sensitivity of both LFCCs varied from 3 V / A turn up to 124 V / A turn in the frequency range 0.14 Hz – 1.00 Hz. Calibration of the ratio of 1 kΩ / 100 Ω using developed RTCC and the equipment of PTB and BIPM showed agreement in measurement results within some parts in 10^{-8}. The realized current comparator is the main ratio standard in a precision ac resistance bridge operated without need of liquid helium which will be one of the main measurement instruments for a future graphene-based quantum Hall resistance standard [4].

Graphene QHE device, fabricated in Aalto University and characterized at dc in MIKES was used in first ac a QHR measurement which was performed in ac QHE setup at PTB. Measurements results showed that the quantum Hall resistance in graphene exhibit a wide, flat plateau without frequency dependent curvature. The graphene device shows only weak frequency dependence similar or even better than for plain GaAs devices without any complex shielding technique applied. The results are promising for the realization of a graphene-based quantum impedance standard operating at lower magnetic field and higher temperature operation [5].

High frequency

JRP IND16 Ultrafast ended in June 2014. MIKES was involved in creating software for uncertainty propagation in signal processing used in digital communications. The communications signal processing software VSA (Vector Signal Analyser), is written in C++ under Digia's open source Qt framework, which has facilities for GUI design and multi-threading. Software runs in two user threads, one handles the display and the other is responsible for the calculations. The VSA software uses the compressed covariance matrix approach and smart jacobians to propagate uncertainty trough the calculations such as error vector magnitude. The software will be freely available for the scientific and industrial community [6,7].

High voltage and power

JRP ENG07 HVDC ended in August 2013. MIKES coordinated the development of a 1000 kV modular DC divider. The uncertainty for measurement at 1000 kV settled to 16 µV/V in laboratory conditions, and CMC entries of 50 µV/V have been submitted [8,9].

The first results of a precision sampler for three-phase measurement of power and power quality were obtained in spring 2014. The bandwidth of the new six channel digitizer is more than 100 kHz. The target uncertainty at 50 Hz is below 1 µV/V in amplitude and 1 µrad in phase displacement between any two channels [10].

The linearity of a high voltage capacitance bridge was studied on 10^{-6} level, and the results were presented at CPEM in Rio de Janeiro [11].

MIKES coordinates ENG61 FutureGrid [12], and takes part in JRP ENG52 SmartGrid II, both running from 2014 to 2017. MIKES has also been involved in revising the IEC standards on high voltage testing and measuring techniques.

Quantum current standard and other applications of single-electron effects

MIKES coordinates EMRP project MICROPHOTON, Measurement and control of single-photon microwave radiation on a chip [13]. The main focus of MIKES is to study the effect of microwave photons on superconducting circuits. An extremely quiet measurement setup with efficient microwave filtering and radiation shielding has been developed. Also, an rf SET (single-electron transistor) setup for a wide measurement bandwidth and minimal back-action has been constructed. The next steps are measurements of hybrid superconductor-normal-metal SET samples that can be used for ultrasensitive microwave spectrum analysis. The goals are, e.g., to minimize the quasiparticle density of superconductors.

MIKES takes part in EMRP project Quantum Ampere to develop a quantum current standard based on hybrid superconductor-normal-metal turnstiles. The main ongoing effort is developing sample fabrication processes for a state-of-the-art electron beam lithography system which is expected to provide the required resolution to achieve sufficient yield and small feature size simultaneously. A three-layer process including a hard germanium mask is developed [14-23].

MIKES has also participated studies on a single-electron pump based on a silicon-based quantum dot with tunable tunnel barriers, in which generation of 80 pA current with uncertainty below 50 ppm was demonstrated [24].

Organizational changes

Starting from 1.1.2015, MIKES will merge with VTT Technical Research Center of Finland. The new non-profit limited company, VTT Oy, is 100 % state-owned, and it has c. 2500 employees.

Low-frequency and impedance

In AIMQuTE MIKES is setting up a Josephson-impedance bridge in a dry cryostat based on two SNS-type Josephson junction arrays delivered by PTB. The arrays have been mounted, but further work is needed to reach 4.2 K with all heat loads. Faster square-wave bias source combining MIKES and PTB amplifiers has been assembled.

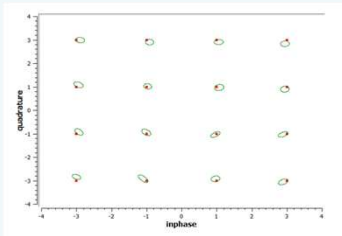
In collaboration with AIVON Oy (Finland) MIKES has been further developing a two-channel AC-voltage source for impedance metrology. With improvements in linearity and output impedance, accuracy of better than 1 ppm in fully digital bridges is feasible. The source is developed also to be used as a transfer standard in Q-Wave project for calibrating analogue-to-digital converters with arbitrary periodic waveforms in audio frequency range [25].

As a collaboration between MIKES and PTB, the PTB AC-Quantum Voltmeter was investigated and a new method for measuring waveforms from digital voltage sources developed [26].

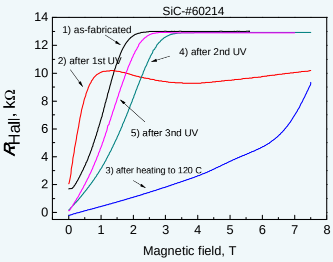
Other research activities

As a part of MIKES's activities in JRP NEW08 MetNEMS, two applications of capacitive microelectromechanical systems (MEMS) have been developed [27]. One of them is a sensitive voltmeter (null detector) in which voltage noise can be suppressed by electromechanical feedback near the pull-in point of the MEMS component. Another application is a stand-alone voltage reference based on the pull-in effect in a MEMS component.

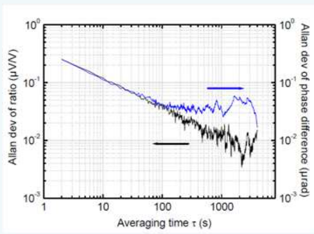
MIKES has also continued activities in developing measurement methods of thermoelectric quantities. In collaboration with Fraunhofer Institute, a new method has been developed for simultaneous measurement of Seebeck coefficient, electrical conductivity, and thermal conductivity. First tests of the method have been performed [28].



High frequency signal processing: *The VSA software showing measured constellation point uncertainty ellipses in green and the ideal constellation in red points (QAM16 signal).*



Quantum Hall effect in graphene: *Example of tuning of carrier density and adjustment of position and shape of i = 2 plateau in epitaxial graphene sample by photochemical method using illumination of the sample with UV light and heating.*



Dual channel precision source: *Allan deviation of amplitude ratio (black) and phase difference (blue) between the two output channels at 1 kHz.*

Power sampler: *Card developed for a multichannel digitizer for three phase power. The key components are LTZ1000 voltage reference and AD7690 successive approximation AD converter with 400 kS/s sample rate and 18 bit resolution.*

Selected publications

1. S. Novikov, N. Lebedeva, and A. Satrapinski "Fabrication and Study of Large Area QHE Devices Based on Epitaxial Graphene", CPEM 2014 Digest, pp. 32-33; full paper submitted to IEEE Trans. Instrum. Meas. (2014).
2. A. Satrapinski, S. Novikov, and N. Lebedeva, "Precision quantum Hall resistance measurement on epitaxial graphene device in low magnetic field", Appl. Phys. Lett. 103, 173509 (2013).
3. S. Novikov, A. Satrapinski, N. Lebedeva, and I. Iisakka, "Sensitivity optimization of epitaxial graphene based gas sensors", IEEE Trans. Instrum. Meas. 62, 1859 – 1864 (2013).
4. A. Satrapinski, H. Pöntynen, M. Götz, E. Pesel, N. Fletcher, R. Goebel, and B. Rolland, "A Low-Frequency Current Comparator For Precision Resistance Measurements", CPEM 2014 Digest, pp. 760-761.
5. C.-C Kalmbach, J. Schurr, F. J. Ahlers, A. Muller, S. Novikov, N. Lebedeva and A. Satrapinski, "Towards a Graphene-based Quantum Impedance Standard", Appl. Phys. Lett. 105, 073511 (2014); http://dx.doi.org/10.1063/1.4893940
6. D. A. Humphreys, P. M. Harris, M. Rodríguez-Higuero, F. Mubarak, D. Zhao, and K. Ojasalo, "Principal Component Compression Method for Covariance Matrices used for Uncertainty Propagation", IEEE Trans. Instrum. Meas , in press (2014); http://dx.doi.org/10.1109/TIM.2014.2340640.
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8. J. Hällström, A. Bergman, S. Dedeoğlu, A P. Elg, E. Houtzager, W. Lucas, A. Merev, J. Meisner, A. Sardi, E.-P. Suomalainen, and C. Weber, "Performance of a wideband 200 kV HVDC reference divider module", IEEE Trans. Instrum. Meas. 63, 2264-2270 (2014).
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11. E.-P. Suomalainen and J. Hällström, "Investigating Linearity of a High Voltage Capacitance Bridge" , CPEM 2014 Digest., pp. 620 – 621.
12. http://futuregrid.emrp.eu
13. A.J. Manninen et al., "Measurement and control of single-photon microwave radiation on chip", CPEM 2014 Digest, pp. 324-325.
14. E. Mykkänen et al., "Recent progress with the SINIS turnstile", CPEM 2014 Digest, pp. 534-535.
15. A. Heimes, V. F. Maisi, D. S. Golubev, M. Marthaler, G. Schön, and J. P. Pekola, "Tunneling and relaxation of single quasiparticles in a normal-superconductor-normal single-electron transistor", Phys. Rev. B. 89, 014508 (2014).
16. T. Aref, A. Averin, S. van Dijken, A. Ferring, M. Koberidze, V. F. Maisi, H. Nguyen, R. M. Nieminen, J. P. Pekola, L. D. Yao, "Characterization of aluminum oxide tunnel barriers by combining transport measurements and transmission electron microscopy imaging", J. Appl. Phys. 116, 073702 (2014).
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