Bureau International des Poids et Mesures

LIST OF INVITED SPEAKERS

BIPM Workshop
« The Quantum Revolution in Metrology »

28-29 September, 2017 - BIPM, Sèvres, France

SESSION 1

PD Dr. Uwe Siegner, PTB

Electrical quantum standards: foundation of electrical units and measurements

Electrical quantum standards are the basis of electrical measurements in the present International System of Units, the SI. In the new SI they will also realize the electrical SI units. In this talk Josephson voltage metrology, quantum Hall resistance metrology, and single-charge transport will be reviewed. Their contributions to fundamental and applied metrology as well as their potential for innovation will be addressed.

PD Dr. Hans Werner Schumacher, PTB

GaAs based single electron pumps for electrical quantum metrology

After the 2018 revision of the SI systems of units a direct primary representation of the revised ampere could be realized by so-called single electron pumps. Single electron pumps are based on single electron transistors that are driven by an oscillating voltage with frequency f. During one oscillation cycle one electron is first captured from source and later ejected to drain thereby generating a quantized current I = ef , with e the charge of the electron.
In my talk I will review the present state of single electron pumps for the direct representation of the ampere. I will show that semiconductor-based single electron pumps are excellent candidates for this task allowing high currents in combination with excellent quantization accuracy. I will further discuss in-situ measurements of pump errors by single charge detection for the realization of a self-referenced quantized current source.

Dr. Wilfrid Poirier, LNE

Practical quantum current standard: performances and perspectives

The ampere, as defined from e in the future SI, can be realized by applying directly Ohm's law to the quantum voltage and resistance standards. I will present a novel programmable quantum current generator (PQCG) able to generate currents in a wide range of values that are quantized in terms of ef_J *(*f_J *is the Josephson frequency) within one part in* 10^8*. I will address its applications and perspectives, notably a compact quantum calibrator based on the graphene resistance standard.*

SESSION 2

Dr. Maria-Luisa Rastello, INRIM

Quantum optical metrology by photons

The present Photonic era is based on rapidly developing optical technology and photon devices, with special impact on the fields of quantum communication, quantum computing, quantum enhanced measurements beyond the standard quantum limit, and optical radiometry.

These applications require quantum optical metrology based on new standards and calibration chains, together with new metrics. In particular, standards are required which operate in the single-photon regime and are embedded in quantum optical technologies.

Moreover, quantum enhanced optical measurements e.g. the exploitation of quantum phenomena such as entanglement and other non-classical state correlations, are among the challenges to yield sensitivity and accuracy better than purely classical approaches. The goal is to develop theoretical and technological capabilities for operating optical systems (e.g. sub-shot noise imaging, ghost imaging, phase measurement) or opto-mechanical systems (micro-cavities), in the quantum regime, beyond the Standard Quantum Limit.

Prof. Dr. Stephan Götzinger, Max Planck Institute for the Science of Light

A single-emitter sub-shot noise quantum light source: press a button and get one photon

In this talk I will discuss our recent progress towards a deterministic single-photon source. By embedding a single molecule into a metallo-dielectric antenna we obtained the most regulated stream of single photons reported to date. Such a source might have potential applications in the calibration of photodetectors and could lead to the redefinition of the candela.

Dr. Ivano Ruo Berchera, INRIM

Quantum imaging: challenges and perspectives in radiometry and biophotonics

Non-classical correlations in optical beams offer unprecedented opportunity of reducing the uncertainty of measurements especially when a low photon flux, down to the single photon level, is used. We review the principles and the state-of-the-art of quantum imaging and sensing techniques with emphasis on the applications to radiometry and biophotonics. In particular, non-classical correlations could represent a cutting-edge tool for investigating phototransduction processes at the fundamental level, such as the one responsible of human vision.

SESSION 3

Prof. Patrick Gill, NPL

Atomic clocks, Superpositions and Entanglement

Progress in atomic clocks has taken advantage from quantum techniques even from the original caesium clock developments using Ramsey's technique of separated field interrogations generating state superpositions. The advent of laser cooling of ions and atoms over four decades ago led to many new quantum operations such as quantum jump detection, cooling to motional ground states in traps, microwave fountain clocks and optical clocks based on single trapped ions or neutral atoms held in optical lattice traps. More recent developments include the dual ion quantum logic clock, and the use of entanglement to achieve frequency instabilities below the standard quantum limit or to measure clock systematic frequency shifts. I will briefly address some of these quantum techniques in atomic clock metrology.

PD Dr. Ekkehard Peik, PTB

Optical clocks with single ions

Following Dehmelt's seminal ideas of using a single trapped ion, laser cooling and the observation of quantum jumps as a spectroscopic signal, optical clocks have now been realized with a systematic uncertainty in the 10^{-18} range. Different elements (Yb, Sr, Al) and different types of reference transitions are investigated. Frequency ratios between these clocks can be measured at an uncertainty that is smaller than in the realization of the SI Hertz with caesium clocks, permitting reliable consistency checks of the new clocks and also searches for new physics like violations of Einstein's equivalence principle.

Dr. David R. Leibrandt, NIST

Optical clock protocols for Heisenberg-limited stability

With the systematic uncertainties of optical atomic clocks fast approaching 10^{-18}, and with new applications in metrology, geodesy, and fundamental physics on the horizon, it is enticing to consider using quantum entanglement to enhance the stability of state-of-the-art optical clocks. Typically, one of the barriers to the use of entangled states is that their decoherence with respect to the local oscillator is more rapid than unentangled states, forcing the use of shorter interrogation times and at least partially nullifying the stability enhancement. This talk presents a brief summary of recent progress on the NIST Al+ quantum-logic clock, and discusses a new protocol for optical clock comparisons that circumvents the local oscillator decoherence limit and that reaches the Heisenberg stability limit for maximally-entangled GHz input states.

SESSION 4

Dr. Gregory F. Strouse, NIST

The Next Generation of Metrology – NIST Quantum SI

With the new definition of the SI currently scheduled to be internationally accepted in 2018, the new SI definition will replace the classical SI [artifact based SI traceability (e.g., kilogram)] with the quantum SI based on quantum phenomena and fundamental and atomic constants. NIST is positioning itself to develop quantum-based standards and sensors to disseminate the quantum SI. These new devices will potentially enable zero-chain SI traceability be enabling NIST to deliver dual standards and sensors to the factory floor. The NIST vision is that these quantum-based innovations will improve the SI dissemination through dual standards and sensors to the point where routine exchange of artifacts for measurement quality assurance is no longer needed. Quantum and photonic based rugged small-scale devices open new horizons in measurement science and represent a disruptive technological shift in how metrology is done. These quantum SI devices draw upon a range of technologies not previously exploited for these applications, such as nanofabrication, photonics, and atomic physics. The NIST next-generation, quantum-metrology programs will be discussed in terms of the larger programmatic view of how quantum-based, chip scale technologies will disrupt the dissemination of the SI through the NIST quantum SI.

Dr. Stephan Schlamminger, NIST

Putting the Quantum into Mechanics: Quantum Standards for mass and force

The Planck constant plays an important role in quantum mechanics, but is not relevant for classical mechanics. It seems therefore surprising that the Planck constant expressed in SI base units is a number times kgm^2s^{-1}*. Contemplating the fact that the unit of mass, the kilogram, is contained in the Planck constant, leads to the conclusion that the most precise determination of the Planck constant must involve a test mass with a mass of 1 kilogram. Because at this cardinal point, the smallest relative uncertainty in mass metrology can be achieved.*

One link between the Planck constant and the unit of mass is the Kibble balance, formerly known as watt balance. This balance establishes a connection between virtual mechanical power and virtual electrical power, which can be measured using the Josephson Effect and the quantum Hall effect as a product of the Planck constant and two frequencies. In the planned revision of the international systems of units (SI), the Planck constant will be fixed and the Kibble balance can be used to realize the unit of mass. The Kibble balance is not limited to mass metrology at 1 kg, but can be used effectively for smaller mass ranges and even to realize forces down to the mN level. For forces well below the mN, the electrostatic balance can be used.

Prof. Dr. Francesco Giazotto, NEST, Istituto Nanoscienze-CNR & Scuola Normale Superiore di Pisa

Coherent caloritronics in superconducting circuits: from heat interferometers to 0-π controllable thermal Josephson junctions

The Josephson effect [1] represents perhaps the prototype of macroscopic phase coherence and is at the basis of the most widespread interferometer, i.e., the superconducting quantum interference device (SQUID). Yet, in analogy to electric interference, Maki and Griffin [2] predicted in 1965 that thermal current flowing through a temperature-biased Josephson tunnel junction is a stationary periodic function of the quantum phase difference between the superconductors. In this scenario, a temperature-biased SQUID would allow heat currents to interfere thus implementing the thermal version of the electric Josephson interferometer.
In this talk I will initially report the first experimental realization of such a heat interferometer [3]. We investigate heat exchange between two normal metal electrodes kept at different temperatures and tunnel-coupled to each other through a thermal device in the form of a DC-SQUID. Heat transport in the system is found to be phase dependent, in agreement with the original prediction. After this initial demonstration, we have extended the concept of heat interferometry to various other devices, implementing the first quantum `diffractor' for thermal flux [4, 5], realizing the first balanced Josephson heat modulator [6], and an ultra-efficient low-temperature hybrid `heat current rectifier' [7, 8], thermal counterpart of the well-known electric diode [9]. The latter structure offers a remarkable heat rectification ratio up to about 140 which allows its implementation in solid-state thermal nanocircuits and general-purpose electronic applications requiring energy harvesting and isolation at the

nanoscale. Finally, I will conclude by showing the realization of a fully superconducting heat modulator based on the first tunable „0-π“ thermal Josephson junction [10], and I will describe the principle for a microwave quantum cooler based on the Josephson effect [11].

References

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SESSION 5

Dr. Kiwoong Kim, KRISS

From Quantum Interference to Human Perception

Superconducting quantum interference devices (SQUID) have widely been used for state-of-the-art precision measurements in various scientific research areas in range of metrology to basic physics. Beyond the fundamental applications, magnetoencephalography (MEG) based on the SQUID technology is the most developed non-invasive brain research tool for studying neuronal dynamics. Measuring and exploring human perception with MEG could give us neurophysiologic guidelines in standardization and quantification of human sensory and cognitive functions. We introduce SQUID-based brain measurement technologies such as MEG and Ultra-low field MRI, and our trials for cognitive measurements.

Prof. Dr. Fedor Jelezko, Ulm University

New approaches for sensitivity and spectral resolution improvement in diamond quantum metrology

In quantum metrology, where the phase of a qubit is used to detect external fields, the clock stability is defined by the qubit coherence time, and therefore determines the spectral linewidth and frequency precision. Here we demonstrate a quantum sensing protocol where the spectral precision goes beyond the sensor coherence time and is limited by the stability of a classical clock. We also discuss the sensitivity improvement of diamond sensors by quantum error correction and show applications of magnetometry enabled by NV defects in diamond.

Dr. Junho Suh, KRISS

Nanomechanical oscillators in the single-phonon regime

Nanomechanical oscillators have been employed as precision sensors in a diverse range of physical measurements. These versatile mechanical sensors reached the single-phonon regime recently as they demonstrate operations near quantum ground states. I will review the current progress in the field and discuss KRISS's approach in applying the nanomechanical oscillators for quantum metrology.

Dr. Jacob Taylor, NIST/JQI

Quantum optical explorations of the nanoscale metrology frontier

I will describe emerging efforts to build and control small systems using quantum optics techniques. This includes magnetometry using individual color centers in diamond, but also transducer systems in which a force is converted into a dimensional change for mechanical systems near their quantum ground state. I examine how these new efforts are changing the paradigm of small-scale metrology.