QuAHMET: Quantum anomalous Hall effect materials and devices for metrology

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***Abstract*—*QuAHMET — Quantum anomalous Hall effect materials and devices for metrology* is a Joint Research Project of the European Metrology Partnership. The project focus is on the traceable measurement and characterisation of quantum anomalous Hall effect (QAHE) materials as devices and primary resistance standard candidates.**

***Index Terms*—Measurement, measurement standards, measurement techniques, measurement uncertainty, precision measurements, uncertainty.**

I. Introduction

The Quantum Hall effect (QHE) is the foundation for the realization of the SI unit of electrical resistance, the ohm (Ω). QHE devices currently employed are based on semiconductors (GaAs heterostructures) and, more recently, on graphene [1]. These devices achieve quantization conditions at low temperatures and high magnetic fields, impeding their adoption beyond national metrology institutes.

The Quantum anomalous Hall effect (QAHE) provides an opportunity to overcome these limitations, whilst maintaining the unsurpassed accuracy expected by primary resistance standards [2].

QuAHMET — Quantum anomalous Hall effect materials and devices for metrology is a Joint Research Project of the European Partnership on Metrology [3]. European Partnerships are a key implementation tool of the European Commission's *Horizon Europe*.

The project focus is on the traceable measurement and characterisation of quantum anomalous Hall effect (QAHE) materials as devices and primary resistance standard candidates. The project is exploring, understanding, and implementing a scientifically grounded methodology for developing metrology grade QAHE devices, accelerating the development of a 'quantum electrical metrology toolbox' for universal adoption of quantum electrical SI standards.

The aim of this summary paper is to have the electrical metrology community at CPEM to become aware of the project, with the aim of involving the interested researchers in its development.

II. Expectations and Objectives

Within the project, the partners will explore and understand in-depth a new but scientifically grounded methodology for developing metrology grade QAHE devices, and to achieve higher operating temperatures compared to the current state-of-the-art. Furthermore, current requirements for extreme experimental conditions and intrinsic material/device limitations of QAHE make accurate measurements non-trivial. To address this, National Metrology Institutes (NMIs) are developing and apply both novel and consolidated measurement methods for metrological assessment of QAHE devices to achieve both best and medium uncertainty ranges, opening the possibility of knowledge transfer beyond NMIs to research laboratories.

The specific objectives of the project are focused on:

1) improving the growth techniques of magnetically doped topological insulator (TI) (e.g., Bi_2Te_3 and Sb_2Te_3). The thin film samples will be fabricated by molecular beam epitaxy on closely lattice matched substrates, for the production of devices optimized for the QAHE. The effects

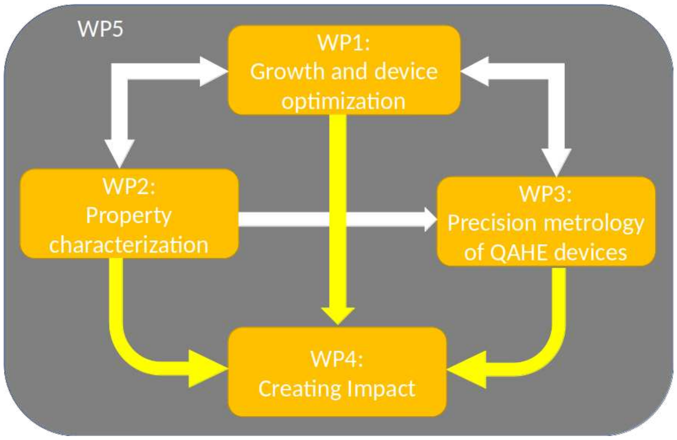

Fig. 1. Graphical representation of the interaction between the five workpackages of the project.

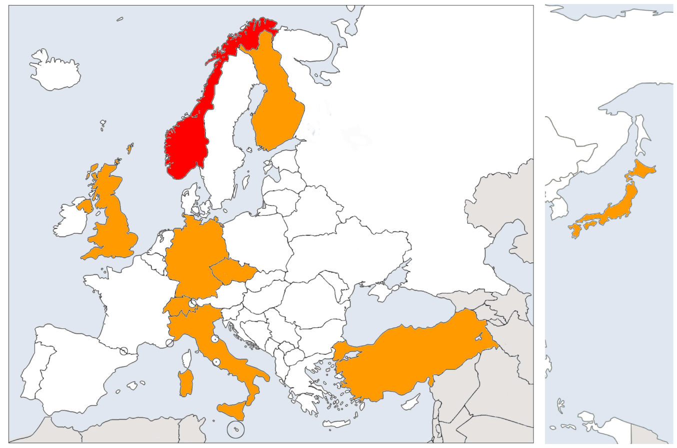

Fig. 2. Map of the project partners.

of anisotropic magnetic insulator layers interfaced with TIs will also be explored.

2) characterising of the electronic, structural, magnetic, and magneto-electronic properties of the fabricated samples in different conditions. These include temperature, current, applied magnetic field, different growth parameters. The aim is to investigate the limitations of QAHE, i.e., low critical temperatures and currents when working on precision growth-control of interfaces.
3) investigating fabricated samples by scanning probes and magnetometry techniques at low temperatures, and the magnetic and structural properties with high lateral resolution.
4) applying precision measurement techniques to the optimized QAHE devices to prove their detailed metrological assessment, both at sub-Kelvin and above $1\,\mathrm{K}$ temperatures, with a target QAHE resistance quantisation accuracy between 1 and 10 parts in 10^6, above $1\,\mathrm{K}$, at currents above $1\,\mu\mathrm{A}$ and at low-to-zero applied magnetic field.
5) encouraging the adoption of the developed technology and measurement infrastructure by standards developing organisations (e.g BIPM), end users interested in applications, such as spintronics and topological quantum computing, and advance the research and progress in the field of TIs.

III. Implementation

The project is divided in four interacting technical workpackages: the structure is displayed in graphical form in Fig. 1. An additional workpackage (the grey background in the picture) is devoted to project management.

The consortium of 14 partners gathers 7 leading European NMIs, the Japanese NMI for metrology, complemented by 6 globally recognized institutes from academia and applied research. A map of the partners' locations is given in Fig. 2.

IV. First results

First results of the project, related to both the device fabrication and the measurement techniques under development, will be given at the Conference.

V. Connect to the project!

The project is committed to open science practices that will be implemented as integral parts of the methodology.

Research institutions, calibration laboratories and instrument manufacturers are welcome to connect to the project as stakeholders. The project will communicate to the interested parties with

- its website[1]
- its Linkedin channel[2]
- its YouTube channel[3]
- its periodic Newsletter

You can connect to the project by sending an email to the Impact workpackage leader, Martina Marzano (m.marzano@inrim.it).

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