Title: Metrology for topological spin structures

Abstract

In 2016, a Nobel prize in physics was awarded for "theoretical discoveries of topological phase transitions and topological phases of matter". In essence, it was revealed that spins in solids have the potential to be arranged in specific topological configurations thus revolutionising magnetic data storage and/or creating new quantum standards. However, more research is needed to develop metrological tools and methods for the characterisation of topological spin structures (e.g. radial vortices or skyrmions) that will facilitate exploitation of this physical phenomenon in practical applications (such as recording media, logic, microwave devices etc.).

Keywords

Topological spin structures, domain walls, bubbles, vortices, skyrmions, multiferroic materials, Dzyaloshinskii-Moriya interaction, Berry curvature, anomalous velocity, anomalous Hall effect, topological Hall effect, anomalous Nernst effect, light-matter interaction

Background to the Metrological Challenges

Fundamental research in the field of spintronics has lead both to highest scientific merits, e.g., the 2007 Physics Nobel Prize for the discovery of giant magnetoresistance, and to extremely fast development of a huge market sector dealing with mass production of consumer and industrial electronics, such as hard disk storage devices. However, there are several high level requirements in this field connecting basic research, metrology, and ability to exploit these structures in novel devices.

There is a need to understand the material parameters of the new materials and systems with stable topologically-protected chiral spin structures. Due to their small size, it is difficult to experimentally access topological spin structures. While high-resolution tools allow the direct observation of skrymions in a vacuum environment, their observation by measurement of the topological Hall effect is highly debated. Therefore, validated measurement methods are needed allowing the identification of specific topologically protected spin structures.

The dynamics of topologically protected spin structures and their characterisation with respect to current- and field-induced motion are of key importance for future applications. While characteristic dynamical modes in the GHz frequency range can provide a means to identify topological phases, reliable metrological tools for the investigation of current- and field-induced dynamics still have to be developed. Additionally, despite theoretical proposals, it is not clear if topological spin systems can serve as novel quantum standards. Future research on topological spin structures not only requires validated measurement tools, but also should be based on reliable modelling. Micromagnetic simulations and analytical tools are required to validate experimental results and to reliably predict novel material properties.

Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The JRP shall focus on the traceable measurement and characterisation of topological spin structures like chiral domain walls, bubbles, radial vortices or skyrmions.

The specific objectives are

1. To develop and validate measurement tools and methods for reliable determination of key material parameters, i.e., Dzyaloshinskii-Moriya interaction (DMI) constant, magnetisation saturation, intrinsic and interfacial anisotropy contributions, relevant for the development of stable topological spin structures.
2. To develop, compare and validate measurement techniques capable of identifying specific nanometre-scale topological spin structures, such as domain walls, bubbles, and skyrmions in different magnetic materials.
3. To develop metrology tools and methods allowing the analysis of the dynamical properties of topological spin structures in the GHz and THz frequency range. These dynamic measurement tools should be capable of capturing the dynamics of topologically protected spin structures such as noise, oscillation modes and propagation. They should also be capable of exploring the Berry phase (resulting from the spatial arrangement of the spins).
4. To provide reliable micromagnetic simulations and analytical tools for the modelling of topological spin structures. To compare experimental and theoretical results on topological-spin-structure dynamics and to verify the dependency between the measured DMI constant and the stability and geometry of topological spin structures.
5. To facilitate take up of the technology developed in the project by end users including guidelines for the accurate characterisation of these topological spin structures and the implementation of new measurement services on the DMI constant.

Proposers shall give priority to work that aims at excellent science exploring new techniques or methods for metrology and novel primary measurement standards, and brings together the best scientists in Europe and beyond, whilst exploiting the unique capabilities of the National Metrology Institutes and Designated Institutes.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.5 M€, and has defined an upper limit of 1.8 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 40 % of the total EU Contribution to the project.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the “end user” community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,

You should detail other impacts of your proposed JRP as specified in the document “Guide 4: Writing Joint Research Projects (JRPs)”.

You should also detail how your approach to realising the objectives will further the aim of EMPIR to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of up to 3 years duration.