Title: Spin current metrology for spintronic devices and materials

Abstract

Spintronics have potential for commercial applications in different sectors, ranging from biosensors to quantum computing. For this reason, the field requires robust tools for validating spintronic devices and materials, as well as an efficient generation and accurate, reliable measurement of spin currents. These measurements are crucial to evaluate the efficiency of spin-current-related phenomena, but metrological protocols and systematic studies are currently lacking. Proposals addressing this SRT should advance spin current metrology by developing novel techniques for spin current measurement and generation and promote the take up of the technology and measurement infrastructure.

Keywords

Spintronics, spin currents, spin current metrology, spintronic devices, spintronic materials, spin current generation, spin currents measurements, data evaluation, spintronic key parameters, metrology

Background to the Metrological Challenges

Spintronics is a promising field of condensed matter physics with the potential for offering new solutions in technological applications that require increased speed, reliability, sensitivity and reduced power consumption. Spin currents can be generated and measured in different ways (e.g. spin Hall effect) and materials (e.g. ferromagnets). Previous work compared some techniques, but these studies were often limited to one material, method or technique, and extended systematic studies were scarce. The most widely used measurement method exploits the spin Hall effect but despite intensive research on the technique, the method is still under discussion, leading to discrepancies for the literature values of the spin Hall angle, which is the most important parameter quantifying spin currents. Measurements of spintronic key parameters suffer from an incomplete analysis of the measurement conditions, which leads to large measuring errors. Models including the measurement conditions can help to reduce this problem, but they are currently lacking.

Measurement methods for spin currents are limited by spin diffusion length and spin lifetime. In metallic samples with short diffusion length and small spin accumulation, some innovative high resolution or thermal imaging techniques were shown to be alternatives to characterise locally spin structures in spintronic devices (e.g. microscopy). However, to obtain a quantitative analysis, calibration procedures are required.

Efficient spin current generation in ferromagnetic materials has been obtained by the spin anomalous Hall effect (among others), but this has proved to be sensible to external parameters (e.g. electric field/light). Novel materials (e.g. non-collinear antiferromagnets) are promising for spin current generation, but many of these require high-risk-high-gain research, due to the highly specialised preparation and characterisation. Furthermore, a complete theoretical and semi-classical picture, describing the mechanisms of spin absorption and charge-spin conversion, especially in strong spin-orbit-coupling regime, is still missing. Furthermore, machine learning techniques, in combination with ab initio or micromagnetic models, were proposed for efficiently determining material properties and their dependency on critical parameters, but these models are not yet applied in the search for efficient spin current materials. Given the strong commercial potential in the near future of spintronics generation and measurement, the European electrical engineering industry, and different sectors (e.g. electronic materials, computing and energy), will need robust tools for the validation of spintronic devices and materials, and reliable measurements of spin currents.

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 development of metrological capacity for spin current in spintronic devices and materials.

The specific objectives are

1. To determine the current level of accuracy and reproducibility of the measurement of spin currents by different experimental set-ups and protocols (e.g. by measuring the spin Hall angle), and to develop recommendations which include techniques and analytical or numerical models for data evaluation.
2. To develop and apply novel techniques for the generation and measurement of spin currents and characterisation techniques for spintronic key parameters. This should consider the thermal generation of pure spin currents and non-invasive thermal measurements the combination of local and non-local techniques and high-resolution optical scanning or magnetic imaging techniques.
3. To improve the efficiency of spin current generation in spintronic materials by (i) using novel spintronic systems (e.g. antiferromagnetic materials, topological insulators, 2D quantum materials and magnetic materials with large spin-orbit coupling), (ii) tuning material properties/external parameters (e.g. resistivity and electric field and light), (iii) applying theoretical models (e.g. continuum magnetization modelling, non-equilibrium thermodynamics and spin accumulation theory), and (iv) developing novel approaches for high spin current efficient materials (e.g. machine learning).
4. To facilitate the take up of the technology, measurement infrastructure and good practice guide developed in the project by the measurement supply chain (NMIs, calibration laboratories), standards developing organisations (e.g. IEC) and end users (in the fields of electronics and nanomaterials).

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 across all selected projects in this TP.

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,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the electronic materials, computing and energy sectors.

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.