Title: Stabilization and Control of Skyrmions in FeGe Thin Films: A New Frontier for Spintronic Applications

ABSTRACT

Magnetism is one of the fundamental properties of materials that plays a crucial role in modern technology. Among countless technological applications of magnetic materials, they are commonly used in data storage, form the basis of electric motors and generators, and are essential in medical imaging techniques. For many years, researchers have been exploring new ways to harness the potential of magnetic materials, especially at the nanoscale, where quantum effects begin to dominate, opening pathways to entirely new technologies, including computing and data storage devices. One of the most promising materials are the structures with a thickness of up to a hundred nanometers, known as magnetic thin films. Downsizing materials to the form of thin films can introduce unique magnetic properties that differ significantly from their bulk counterparts. Thin films are particularly important in the field of spintronics, a branch of science that goes beyond traditional electronics by utilizing not only the electron's charge but also its intrinsic spin (magnetic moment) to create non-volatile, ultra-fast, and energy-efficient memory or computing technologies. To fully realize the potential of thin-film applications in spintronics, new methods of control of the magnetic properties at the nanoscale must be developed. A particularly interesting discovery in thin-film magnetism and spintronics are skyrmions - nanometric, swirling magnetic topologiical structures. Studies show that these magnetic "whirlpools" can behave like quasiparticles, meaning they can be moved or manipulated with minimal energy, making them promising candidates for next-generation low-power, high-speed data storage and processing technologies. However, reliably controlling skyrmions, especially at room temperature, remains a significant challenge. This SONATINA project focuses on FeGe (iron germanide), a unique magnetic material with a an ability to form skyrmions near room temperature due to the occurrence of Dzyaloshinski-Moriya interaction (DMI), making it an excellent candidate for practical applications. However, the magnetic properties of FeGe in thin-film form remain largely underexplored. Within the frame of the project, ultra-thin layers of FeGe and multilayers with FeGe will be grown and magnetically characterized. The properties of FeGe will be investigated systematically by carefully tuning factors such as film thickness, epitaxial strain due to substrate lattice mismatch, DMI modulation or external stimuli like current pulses and dynamic strain. This SONATINA project will also explore how FeGe thin films in contact with other magnetic materials might be affected by the so-called magnetic proximity effect, which can modify magnetic properties of FeGe. Furthermore, modification of FeGe properties due to the contact with heavy metal will be explored, since a heavy metal (e.g. Pt, Ir) can significantly affect the DMI within the material. Thus, it can modify the stability and possible formation of skyrmions. One of the key outcomes of the project is the creation of stable, room-temperature skyrmions without the need for external magnetic fields, which is a crucial step toward making them viable for next-generation spintronic technologies. To achieve this, advanced experimental techniques will be used, including synchrotron-based X-ray Absorption Spectroscopy (XAS) and X-ray Photoelectron Emission Microscopy (XPEEM) with polarization dependent dichroic effects of X-ray Magnetic Circular(Linear) Dichroismy – XMC(L)D at specialized facilities like the National Synchrotron Radiation Centre SOLARIS in Krakow and the ALBA Synchrotron in Barcelona. These methods will unveil the magnetic properties of ultra-thin FeGe films and allow the visualiazation of skyrmions at the nanoscale. In ALBA Synchrotron instrumentation using time-resolved XPEEM imaging the project will establish how skyrmion magnetic dynamics can be efficiently controlled with current pulses or dynamic strain. It is an essential feature for developing skyrmion-based spintronic devices. Synchrotron radiation methods will be also complemented by laboratory based magneto-optic Kerr effect (MOKE) microscopy and magnetometry. The outcomes of this research will advance the fundamental understanding of skyrmion magnetism. By investigating the potential of skyrmions, this project will contribute to the development of next-generation computational and memory devices.