Università di Genova | Dipartimento di Fisica

PhD annual report

PhD student: Antonio Bianco.

Supervisors: Prof. Daniele Marré (UniGe), Dr. Ilaria Pallecchi (CNR-SPIN).

Scientific Research activities

My research aims to explore the fundamental properties of van der Waals (**vdW**) materials and to develop **novel electronic devices** based on them, a platform that holds great promise both for basic science and emerging technologies. My main activities focus on:

- The conception and study of novel vdW-based electronic devices for **spintronics applications.**
- The exploration of the electronic properties of **vdW magnetic topological compounds**.

Van der Waals magnetic topological compounds are the ideal platforms to investigate the interplay between **magnetism** and **topology**. Their layered crystal structure allows mechanical exfoliation down to the monolayer limit, and reducing the thickness offers the opportunity to study the evolution of the electronic band structure.

My research began with my Master's thesis on bulk $MnSb_2Te_4$, where I investigated the relationship between **topology** and **anomalous transverse signals** through electrical and thermoelectric measurements. In my PhD, I am extending this work by fabricating $MnBi_2Te_4$ **nanodevices** to study the transport properties of $MnBi_2Te_4$ flakes, in collaboration with Dr. Michele Ceccardi (UniGe) and under the supervision of Dr. Federico Caglieris (CNR-SPIN).

This effort required overcoming several intermediate steps:

- **Mechanical exfoliation** of $MnBi_2Te_4$ followed by **deterministic transfer** of the flakes onto pre-patterned substrates with Au pads created by optical lithography, in collaboration with Dr. Nicola Manca (CNR-SPIN).

- Fabrication of electrical contacts by **thermal-scanning probe lithography** (Nanofrezor Instruments), thanks to a collaboration with Dr. Giorgio Zambito (UniGe), Prof. Maria Caterina Giordano (UniGe) and Prof. Francesco Buatier De Mongeot (UniGe).
- **Optimization of electrical contact quality** through argon-plasma pre-etching and in-situ Ti/Au deposition, in collaboration with Dr. Francesca Telesio (UniGe), using Kenosistec instrument at DifiLab.

Spintronics is an emerging paradigm that exploits the electron **spin**, in addition to its charge, to process and store **information**. It holds great promise for **magnetic memory** technologies and for exploring **quantum magnetic phenomena**. A key breakthrough in this field is the discovery of current-induced torques, typically realized in heterostructures combining a non-magnetic material with strong spin–orbit coupling and a ferromagnet. In these systems an electrical current in the non-magnetic layer can manipulate the magnetization of the ferromagnetic one. These heterostructures form the basis of next-generation magnetic memories, spin-orbit magnetic RAM (SOT-MRAM), in which current-driven magnetization control allows for greater **miniaturization** than magnetic memories driven by an external magnetic field.

One of my main objectives is to investigate **current-induced torque** in transition metal dichalcogenides (**TMDs**), a class of van der Waals materials composed of compounds containing a transition-metal element and a chalcogen. To achieve this, I have carried out several studies during the first year of my PhD, including:

- The mechanical exfoliation of vdW materials, focusing first on MoS_2 as a non-magnetic material. Molybdenum disulfide is widely employed in 2D applications, but its spintronic properties remain largely unexplored. Moreover, theoretical calculations by Dr. Alessio Filippetti (UniCa) and Dr. Fabio Bernardini (UniCa, CNR-IOM), carried out as part of this project, indicate that MoS_2 is a promising candidate for spintronic—more precisely, **orbitronics**—applications. In addition, I have also considered other TMDs such as WTe_2, $SnSe_2$, and $MoTe_2$.
- I have studied a **new design** of current-induced torque devices to test the ability of MoS_2 to switch the magnetization of the ferromagnetic layer, using a non-local spin-valve geometry.
- Developing a **protocol to fabricate van der Waals heterostructures** in a reproducible way, allowing control over the stacking of the layers with micrometric precision.
- Together with Dr. Raimondo Cecchini (CNR-ISMN), I designed the lithography pattern, which was subsequently realized using **electron-beam lithography** by Dr. Cecchini.

- I performed electrical **transport measurements** on the final device, which confirmed that it operates as a current-induced torque device with good energy efficiency, making it promising for applications.

Conferences

[1] ***SPEAR Conference on Spin-orbitronics & 3rd Orbitronics Workshop***, CIC Nanogune - San Sebastian, Spain. (**Poster**, Highly efficient field-free switching by orbital Hall torque in a MoS2-based device operating at room temperature**)**.

[2] ***FISMAT2025*** , Università Ca'Foscari Venezia and Consorzio Nazionale Interuniversitario per le Scienze fisiche della Materia-Venice, Italy. (**Oral contribution**, Highly efficient field-free switching by orbital Hall torque in a MoS_2-based device operating at room temperature)

Publications

*Submitted to PRR***:**

- Antonio Bianco, Michele Ceccardi, Raimondo Cecchini, Daniele Marré, Chanchal K. Barman, Fabio Bernardini, Alessio Filippetti, Federico Caglieris and Ilaria Pallecchi, "*Field-free switching by current-induced torque in a MoS2-based device operating at room temperature*"

In preparation:

- Antonio Bianco, Michele Ceccardi, Ilaria Pallecchi,…, Anna Isaeva, Daniele Marrè and Federico Caglieris *"Electric and Thermoelectric anomalous transport properties of* $MnSb_2Te_4$*"*

Attended courses

- Energetics in the quantum regime (Prof. D. Ferraro).
- Introduction to nanophotonics and nanofabrication (Prof. M.C. Giordano).
- Advanced Crystallography: theory and experiments (Prof. A. Martinelli).