Università di Genova

PhD Annual Report

PhD Student **Ceccardi Michele**

Supervisors Prof. D. Marré (Unige)
Dot. F. Caglieris (CNR-SPIN)

My PhD thesis is about the investigation of Van der Waals topological materials, in which a layered structure is combined with a non-trivial band topology, studying the thermoelectric transport properties.

I have been measuring the electric and thermoelectric transport properties of exfoliated flakes of $MnBi_2Te_4$, a magnetic topological insulator, as already addressed in the previous reports. In the final year, I have studied a 20nm-thick sample, approaching the 2D limit and I have tuned its properties by a $SrTiO_3$ based field effect device. The interplay between a magnetic topological insulator and a complex oxide is the perfect playground to explore fascinating phenomena. Firstly, the unique properties of the $SrTiO_3$ substrate allow a band filling control in the exfoliated flakes, enhancing an anomalous contribution that is appearing at low temperature and high magnetic fields. The field effect control is evidencing the topological nature of the effect that could be related to the theoretically predicted field induced Weyl cones in the band gap. At the same time, the sensibility of the nano-structures to the external environment is able to show a complex evolution in the oxide in response to the field effect. Interestingly, as already discussed in the Ref. 1, the application of an external magnetic field is proven to be a powerful external knob for realising and controlling the topologically protected phases.

Moreover, another material under study was layered trigonal $PtBi_2$, a non-magnetic Weyl semimetal that is also hosting superconducting Fermi arcs. The intrinsic combination of non-trivial topology with superconductivity opens the route to novel quantum devices.
During the second year of PhD, I addressed the Nernst effect of a millimetric bulk single crystals. Although the general amplitude of Nernst effect can be picked up within a semiclassical model, several unconventional features remain doubtful and the related manuscript is currently under review (Ref. 3).
In the final year, I have reduced the dimensionality of the samples under study, investigating a 150nm-thick exfoliated flake, during a guest period of six months at the IFW institute in Dresden, Germany, under the supervision of Prof. Bernd Büchner. Rotating the magnetic field in the plane of the sample, the angular dependence of the longitudinal and the transverse electric signals has been measured. Superimposed to a π periodic modulation, which could be related to chiral anomaly, an anomalous signal has been unravelled. The latter shows the same 2π/3 periodicity of the crystal and the manuscript in Ref. 4 is evidencing its topological nature, providing a possible theoretical explanation. Once again, the experimental findings are evidencing the key role of the external magnetic field in the study of topological phases.
Furthermore, I have measured the angular dependence of the thermoelectric transport properties of the 150nm-thick flake, reporting not only the π periodic modulation, but also the 2π/3 periodic component once again. On the one hand, the former could represent the first experimental observation of planar Nernst effect due to chiral anomaly. On the other, the latter is enriching the theoretical discussion about the topological contribution.

In addition, I have been working in collaboration with the Physical Chemistry group of the university of Genoa, lead by Pietro Manfrinetti, to characterize the transport properties of new synthetized compounds (Ref. 2,6).

Finally, besides the involvement in the PRIN 2022 projects "TOTEM" to explore and manipulate the topological phases in hexagonal ternary compounds, and "SUBLI", to create spin generators based on Van der Waals dichalcogenides, I have also opened a new fruitful collaboration during the period in Dresden. I worked intensively with the "Superpuddles group", lead by Prof. Nicola Poccia, to measure the thermoelectric transport properties of atomically thin flakes of superconducting $Bi_2Sr_2CaCu_2O_{8+x}$. The related manuscript is currently under review (Ref. 5). The activity gave me the opportunity to gain experience in measuring the transport properties of air-sensitive atomically thin sample. In particular, I have worked in an argon filled glovebox, using nanomembrane microprinted circuit boards to both create the electric contacts and encapsulate the samples.

Conferences and workshops

1. Superconducting and topological materials, joint workshop IFW Dresden -University of Genoa in *Genoa*, *Italy*. (Oral contribution, *"Transport investigation of t-$PtBi_2$" on behalf of Dr. Joseph Dufouleur (IFW)).*
2. DPG spring meeting 2024 in *Berlin*, Germany (Oral contribution: *"Anomalous Nernst effect in topological and magnetic material $MnBi_4Te_7$"*).

Programmed activity:

3. MesoSchool 2024, school of Mesoscopic Physics in Cargèse, *France.*

Publications

1. M. Ceccardi, A. Zeugner, L. C. Folkers, C. Hess, B. Büchner, D. Marré, A. Isaeva and F. Caglieris*. *Anomalous Nernst effect in magnetic and topological material $MnBi_2Te_4$*. npj Quantum Materials, 8, 76 (2023)
2. A. Martinelli, G. Lamura, P. Solokha, A. Provino, C. Bernini, M. Ceccardi, M. Pani, M. Ferretti, S.K. Dhar, P. Manfrinetti. *Crystal structure and physical properties of the new $AcNi_6Si_6$ compounds (Ac: Th, U)*. Journal of Alloys and Metallurgical Systems, 5, 100051 (2024)

Submitted works:

3. F. Caglieris, M. Ceccardi, D. Efremov, G. Shipunov, S. Aswartham, A. Veyrat, J. Dufouleur, D. Marré, B. Büchner and C. Hess. *Multi-component Nernst effect in superconducting Weyl semimetal t-$PtBi_2$.*
   The manuscript has passed the editorial step in Physical Review Letters.
4. A. Veyrat, K. Koepernik, L. Veyrat, G. Shipunov, S. Aswartham, J. Qu, A. Kumar, M. Ceccardi, F. Caglieris, N. P. Rodrıguez, R.Giraud, B. Büchner, J. van den Brink, C. Ortix and J. Dufouleur. *Dissipationless transport signature of topological nodal lines.*
   The manuscript has passed the editorial step in Nature Physics.
5. *S. Shokri, M. Ceccardi, T. Confalone, C. N. Saggau, Y. Lee, M. Martini, G. Gu, V. M. Vinokur, I. Pallecchi, K. Nielsch, F. Caglieris and N. Poccia. Evolution of dissipative regimes in atomically thin $Bi_2Sr_2CaCu_2O_{8+x}$ superconductor.* The manuscript has passed the editorial step in Advanced electronic materials.
6. M. Mödlinger, A. Provino, P. Solokha, S. De Negri, F. Caglieris, M. Ceccardi, C. Bernini and P. Manfrinetti. *Crystallochemistry, Thermodynamic and Physical Properties of the novel intermetallic compound Cu_{3-x} (As,Sb).*
   The manuscript has passed the editorial step in Intermetallics.

Exams given

- **Fondamenti di Computazione Quantistica** (1 slot, Prof. P. Solinas)