Università di Genova

PhD Annual Report

PhD Student **Ceccardi Michele**

Supervisors Prof. D. Marré (Unige)
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My PhD thesis is about thermoelectric transport properties of Van der Waals topological materials, in which a layered structure is combined with a non-trivial band topology. These systems are the perfect playground to tune the topological properties, through a fine control of their dimensionality.

During the second year, most of my activity was dedicated to the study of **exfoliated flakes of** $\boldsymbol{MnBi_2Te_4}$. The compound, that is classified as a **magnetic topological insulator**, exhibits a plethora of fascinating topological properties finely controlling the number of layers. Starting from bulk single crystals, I obtained desired samples with thickness that ranges from 10 nm (few layers regime) to 40 nm (bulk regime), performing mechanical exfoliation by scotch-tape and PDMS (a viscoelastic material). Hence, I transferred them onto a $SrTiO_3$ substrate, performing a deterministic dry transfer, using a micromanipulator and a PDMS sheet.
Moreover, we are developing a suitable procedure to measure the electric and the thermoelectric transport properties of the exfoliated flakes. We are creating electric contacts by **NanoFrazor** instrument, thanks to an internal collaboration with Giorgio Zambito, prof. Marina Giordano and prof. Buatier De Mongeot in the department. The thermal scanning probe lithography (t-SPL) lets us make devices by designing custom Au/Ti patterns with nanometric resolution without damaging the few layers samples. In addition, we realized a special set-up equipped with a grounding circuit to prevent the accumulation of charges and static electric fields that can damage the microstructures. Since the contact resistance between the lithographic Au and the flake is still high, we performed a subsequent W deposition by Focus Ion Beam (**FIB**), thanks to Dott. Marine Schott and Prof. Luca Repetto in the department. We phenomenologically observed that the metallic deposition in the contact region can reduce the resistance of three order of magnitude.
Using these techniques, we characterized the electric and thermoelectric transport properties of a 40nm-thick sample. The measurements are very promising since we not only probed the on-chip **thermoelectric signal** of the exfoliated flake at low temperature, but we also strongly modulated the carrier concentration by a **field effect device**, observing a drastic change of the transport properties. The magnitude of the effect and the real action on the sample is still under debate, but the work in this direction is in progress. Furthermore, we are also working to optimize the lithographic process to improve the contact resistance between the lithographic Au and the flake.

Another sample under the glance is the layered trigonal $\boldsymbol{PtBi_2}$, that is a **topological Weyl semimetal**, which shows also a an unusually robust **low dimensional superconductivity** -at very low temperatures- in thin exfoliated flakes. We characterized the **Nernst effect** of a millimetric **bulk single crystals** of this compound and the measured signal deserves further studies, considering that it cannot be ascribed to a conventional quasi-particle behavior. We are currently preparing a publication on this topic (Ref.4). This work is done in cooperation with the **IFW institute of Dresden.**

In addition, as I reported in the previous report, we are investigating the effect of the application of a moderate **uniaxial strain on transport properties** of bulk samples of semimetallic transition metal dichalcogenides $\boldsymbol{(W_{1-x}Mo_x)Te_2}$ for x = {0%, 6%, 15%, 35%, 90%, 100%}. The compounds are classified as

topological Weyl semimetals. The comprehension of the band structure modification driven by the strain and the resulting interpretation of the experimental data is challenging. The work is in collaboration with the **IFW institute of Dresden.**

Concerning topological materials, I am also involved in the PRIN 2022 project **TOTEM** lead by Federico Bisti (Università degli Studi dell'Aquila). The aim of the research activity is to explore and manipulate the topological phases. The project assumes as materials of choice the family of the hexagonal ternary compounds (e.g. $\boldsymbol{BaAgBi}$, $\boldsymbol{SrAgBi}$, $\boldsymbol{CaAgAs}$, $\boldsymbol{SrAgAs}$), since predicted to exhibit Dirac nodes near the Fermi level.

In addition, I was also involved by Ilaria Pallecchi (CNR-SPIN) in another other research project, that was financially supported by the FLAG-ERA JTC2017 Project No. **MELODICA**. The project was aimed to study the thermoelectric transport properties of **Van der Waals dichalcogenides**. In the work of the Ref. 1, I used the exfoliation techniques to realize a field effect device for the measurements the thermoelectric transport properties of a $\boldsymbol{SnSe_2}$ flakes.
The Van der Waals dichalcogenides have remarkable potential not only for thermoelectricity, but also for spintronics. I am involved in the PRIN 2022 project **SUBLI**. The aim of the research activity is to explore the possibility of developing the spintronic equivalent of thermoelectric energy harvesting realizing **spin generators**, based on Van der Waals dichalcogenides (i.e. $\boldsymbol{MoS_2}$).

Conferences

1. **Superconducting and topological materials**, joint workshop IFW Dresden - University of Genoa in Dresden, Germany. (**Oral contribution,** *"Transport properties of $(W_{1-x}Mo_x)Te_2$ semimetals under uniaxial strain")*
2. **Workshop on magnetic topological materials** in Herzberg, Swiss. (**Poster,** "Weyl cones induce anomalous Nernst effect in a magnetic topological material $MnBi_4Te_7$")

Publications

1. Ilaria Pallecchi, Federico Caglieris, Michele Ceccardi, Nicola Manca, Daniele Marré, Luca Repetto, Marine Schott, Daniel I. Bilc, Stefanos Chaitoglou, Athanasios Dimoulas, and Matthieu J. Verstraete. *"Investigation and field effect tuning of thermoelectric properties of $SnSe_2$ flakes", Phys. Rev. Materials 7, 054004, 2023*
2. Marianne Mödlinger, Alessia Provino, Pavlo Solokha, Federico Caglieris, Michele Ceccardi, Daniele Macciò, Marcella Pani, Cristina Bernini, Dario Cavallo, Andrea Ciccioli and Pietro Manfrinetti. *"Cu3As: Uncommon Crystallographic Features, Low-Temperature Phase Transitions, Thermodynamic and Physical Properties"*, Materials, 16, 2501, 2023

Submitted to npj Quantum Materials:

3. Michele Ceccardi, Alexander Zeugner, Laura Folkers, Christian Hess, Bernd Büchner, Anna Isaeva, Daniele Marré, Federico Caglieris. "*Weyl cones revealed by the anomalous Nernst effect in $MnBi_4Te_7$*"

Under preparation:

4. F.Caglieris et al.; "Fermi surface evolution in *$PtBi_2$* probed by Nernst effect"

Attended courses

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