Annual Report

Student: Marzia Ferrera (XXXIV cycle – 3rd year)

Supervisors: Dr. Francesco Bisio and Prof. Maurizio Canepa

ACTIVITY

During my third-year PhD studies, my research activity was primarily focused on the realization of hybrid systems composed of metallic nanostructure and transition metal dichalcogenides, and their characterization by a wide-range of laterally-resolved spectroscopic techniques. The combination of two-dimensional semiconductors with nanometric metallic objects is, indeed, extremely appealing since it provides a promising playground to tune their local optoelectronic properties. In details, I performed two principal experimental studies.

In the first experimental investigation, WS_2 flakes grown via chemical vapor deposition (CVD) were transferred on top of gold nanoparticles (Au NPs) on lithium fluoride (LiF). The WS_2 flakes and the Au NPs were separated by a LiF spacer characterized by a thickness gradient. Half of the surface of the plasmonic substrate was composed of an ordered array of Au NPs on pre-nanopatterned LiF surface, while, in the other half of the sample, the NPs were randomly arranged on the LiF surface. By exploiting optical characterization techniques with a spatial resolution at the microscale, such as micro-PL and micro-transmittance spectroscopies, the effect on the excitonic properties of WS_2 of both the different arrangement of Au NPs and the thickness of dielectric spacer was investigated.

The second experimental study was performed during my three-month stay within Professor Zahn's Semiconductor Physiscs Research Group at the Technische Universität (TU) Chemnitz (Germany), in the framework of a scholarship awarded by the DAAD (Deutscher Akademischer Austauschdienst). According to the research project outlined in my proposal "Nanospectroscopy of hybrid metallic nanostructures-transition metal dichalcogenide systems", we fabricated a hybrid system composed of a mechanically exfoliated monolayer MoS_2 flake transferred on top of hexagonally arranged gold nanotriangles (Au NTs) on SiO_2/Si. The properties of the system were investigated at the nanoscale by means of tip-enhanced photoluminescence spectroscopy (TEPL). Special emphasis was given to the possibility of simultaneously controlling in the quantum tunnelling regime the emission properties of both ML-MoS_2 and the plasmonic cavity formed by the AFM Au tip and the Au NT by tuning the size of the plasmonic cavity (nm to pm) *via* tip-sample distance variation. Moreover, the effect played by Au nanostructures on the ML-MoS_2 PL quenching rate as a function of the plasmonic cavity size was investigated.

Apart from the research activity on the hybrid systems, at TU Chemnitz I had also the opportunity to use state-of-the-art instrumentation (Accurion EP4 Nnofilm) to perform imaging spectroscopic ellipsometry. The high sensitivity combined with the lateral resolution in the micrometre range made possible to locally map the optical properties of CVD-grown WS_2 flakes transferred on top of appropriate substrates. Particular interest was directed towards the study of the influence of the stacking (2H and 3R) on the optical properties of bilayer regions of the flakes. Moreover, the effect of the dielectric environment on the main excitonic characteristics of WS_2 was investigated. For this last purpose, the flakes were transferred onto different substrates, and combined into heterostacks with other two-dimensional materials, such as hexagonal-boron nitride.

The CVD growth and transfer of WS_2 flakes was performed by Dr. Coletti's Research Group, 2D Materials Engineering Research Line at CNI@NEST-IIT (Pisa, Italy).

PUBLICATIONS

- M. Magnozzi, T. Pflug, **M. Ferrera**, S. Pace, L. Ramò, M. Olbrich, P. Canepa, H. Ağircan, A. Horn, S. Forti, O. Cavalleri, C. Coletti, F. Bisio, M. Canepa, *Local optical properties in CVD-grown monolayer WS_2 flakes*, The Journal of Physical Chemistry C, 125, 16059-16065 (2021) https://doi.org/10.1021/acs.jpcc.1c04287
- **M. Ferrera,** *Plasmonic and interband excitations of Au nanoparticles lead to different relaxation pathways.* Il Nuovo Cimento C, 44, 1 (2021) http://dx.doi.org/10.1393/ncc/i2021-21008-7
- M. Sygletou, S. Benedetti, **M. Ferrera**, G. M. Pierantozzi, R. Cucini, G. Della Valle, P. Carrara, A. De Vita, A. di Bona, P. Torelli, D. Catone, G. Panaccione, M. Canepa, F. Bisio, *Quantitative ultrafast electron-temperature dynamics in photo-excited Au nanoparticles*, Small, 17, 2100050 (2021) https://doi.org/10.1002/smll.202100050

- S. Pace, **M. Ferrera**, D. Convertino, G. Piccinini, M. Magnozzi, N. Mishra, S. Forti, F. Bisio, M. Canepa, F. Fabbri and C. Coletti, *Thermal stability of monolayer WS_2 in BEOL conditions*, Journal of Physics: Materials, 4, 024002 (2021) https://doi.org/10.1088/2515-7639/abd4f2

CONFERENCES

- **Finalist at the Nottingham Prize Competition – 80th Physical Electronics Conference**, a virtual event hosted by Lawrence Berkeley National Lab (Berkeley, California). December 8, 2020
  Oral: Ultrafast temperature evolution in plasmonic Au nanoparticles: a model-free approach.
  https://sites.google.com/lbl.gov/physicalelectronicsconference/nottingham-prize-finalists
- **META 2021, the 11th International Conference on Metamaterials, Photonic Crystals and Plasmonics,** July 20-23, 2021, online.
  Oral: Local variations in light absorption and emission in monolayer WS_2 flakes.
  https://metaconferences.org/ocs/files/META21_program.pdf
- **WSE 11, 11th Workshop Ellipsometry,** September 6–8, 2021, Steyr (Austria).*
  Poster: Spectroscopic imaging ellipsometry of CVD-grown WS_2 flakes.
  https://www.jku.at/en/linz-school-of-education/news-events/11th-workshop-ellipsometry-wse-11/program
- **107th National Congress Italian Physical Society,** September 13–17, 2021, online.
  Oral: Quantitative ultrafast electron temperature dynamics in photo-excited Au nanoparticles.
  https://en.sif.it/activities/congress/107
- **EOSAM 2021, the European Optical Society Annual Meeting,** September 13–17, 2021, Rome (Italy).
  Oral: Ultrafast temperature dynamics of Au nanoparticles: a model-free approach.
  https://www.conftool.com/eosam2021/index.php?page=browseSessions&form_session=272
- **Invited to take part to the Emerging Leader Celebration,** September 20, 2021, IOPmaterials Twitter.
  Poster: Local excitonic properties of hBN-encapsulated CVD-grown WS_2 flakes.
  https://ioppublishing.org/emerging-leader-celebration/
  In this regard, I was invited to contribute with a paper to the Special Issue "Emerging Leaders 2021" of the Journal of Physics: Condensed Matter (JPCM)

AWARDS AND SCHOLARSHIPS

- **12.04.2021 – 11.07.2021 | DAAD (Deutscher Akademischer Austauschdienst) Short-Term Research Grant.**
  Proposal: Nanospectroscopy of hybrid metallic nanostructures-transition metal dichalcogenide systems.
  Place: Technische Universität Chemnitz (Germany)
- **11.2020 | Second Prize as Best Communication (Solid State Physics)** presented at the 106th National Congress Italian Physical Society (SIF)

SEMINARS

- **05.07.2021 - Seminar talk "Controlling excitons at the quantum tunnelling regime in a hybrid plasmonic/2D semiconductor interface"**. Semiconductor Physics Research Group, TU Chemnitz (Germany).
- **10.05.2021 - Online seminar "Raman and Photoluminescence spectroscopies"**
  Course: Metodi Ottici e Spettroscopici per lo Studio dei Materiali, Master's Degrees in Physics and Materials Science and Engineering, Physics Department, Università di Genova.

OTHER ACTIVITIES

- **Tutoring activity** in General Physics – Bachelor's Degree course in Naval Engineering – A.Y. 2020/2021

* I gave contribution to the poster preparation. I was not able to attend the Conference in person.