Ph.D. course in Physics and Nanoscience - XXXVII cycle

2nd year report – Ermes Peci

Supervisors: Dr. F.Bisio and Prof. M.Canepa

RESEARCH ACTIVITIES

The central topic of my Ph.D. research activity is the investigation of two-dimensional systems made of transition metal dichalcogenides (TMDCs), such as WS_2 and MoS_2. These atomic-thick materials exhibit intriguing optical and electronic properties, and they can be exploited as functional layers in novel devices.

During the second year of my Ph.D. project, I focused on the optimization of the exfoliation process in order to obtain large-area monolayer flakes of 2D TDMC. We obtained mm-sized flakes of MoS_2 and hundreds-of-µm-sized flakes of WS_2 by means of an innovative method christened gold-assisted exfoliation of bulk crystals on functionalized substrates. This recipe allows to easily produce batches of samples of TMDCs with large area and high crystalline quality, overcoming the limitations in size, quality, and quantity of other techniques, like chemical vapor deposition or scotch-tape exfoliation.

The role of the molecule adopted for substrate functionalization (APTES) and its effects on the 2D crystal have been investigated by means of imaging spectroscopic ellipsometry, X-ray photoelectron spectroscopy, Raman and photoluminescence spectroscopies, and atomic force microscopy. The development of the exfoliation recipe and the sample characterization have been performed together with Nicolò Petrini (3rd-year Ph.D. student at UniGe/IIT Genova) and Emma Spotorno (master student in the OptMatLab group). While exfoliation on SiO_2/Si substrates proved satisfactory, we found the method does not work on transparent substrates, such as silica or indium tin oxide. The reason for this behavior is currently under investigation. Moreover, selective patterning at the sub-mm scale of APTES was developed in order to compare the MoS_2/APTES/SiO_2 and MoS_2/SiO_2 systems within the same 2D crystal. The patterning process is currently under optimization.

Furthermore, MoS_2 obtained by means of gold-assisted exfoliation exhibits a strong temporal evolution of the photoluminescence yield upon laser excitation, increasing by more than one order of magnitude. This phenomenon is under investigation by means of tip-enhanced Raman spectroscopy and tip-enhanced photoluminescence spectroscopy. The analysis is being carried out in the framework of a collaboration between our group and Prof. Dietrich R.T. Zahn's group at Technische Universität Chemnitz and will involve a visiting period a TU Chemnitz of around 3 months, starting from Aug 28th, 2023.

Large-area MoS_2 monolayers fabricated as above have also been exploited by Lorenzo Ramò (3rd-year Ph.D. student in the OptMatLab group) and Valentina Venturino (master student in the OptMatLab group) for building plasmonic-2D semiconductor hybrid systems. This internal group cooperation has the final goal of developing a nanothermometer to study heat transfer at the nanoscale.

A further activity carried out in this year has been the ellipsometric characterization of Au, Cr, and Al oxide thin films, as well as synthesized monolayers of MoS_2. This work has been performed within a collaboration with Nathan Ullberg and Prof. Vincent Derycke's group at Université Paris-Saclay. The availability of accurate optical constants, obtained by means of spectroscopic ellipsometry, make it indeed possible to optimize the optical contrast of 2D materials while performing backside absorbing layer microscopy (BALM). This project has the final goal of studying the charge dynamics of MoS_2 through an integrated analysis involving BALM and imaging ellipsometry measurements on voltage-gated systems.

CONFERENCES AND SCHOOLS

E-MRS 2022 Fall Meeting, Warsaw (Poland), September 19-22, 2022. Poster presentation: *Probing the Dielectric Function of Two-Dimensional Tungsten Disulfide in Homo- and Heterobilayer Stacking.*

2D Quantum Matter Summer School, Lucca (Italy), July 10-13, 2023.

PUBLICATIONS

Published articles:

E.Peci, M.Magnozzi, L.Ramò, M.Ferrera, D.Convertino, S.Pace, G.Orlandini, A.Sharma, I.Milekhin, G.Salvan, C.Coletti, D.R.T.Zahn, F.Bisio, M.Canepa, *Dielectric Function of Two-Dimensional Tungsten Disulfide in Homo- and Heterobilayer Stacking.* Advanced Materials Interfaces, 2023, 10.3: 2201586

M.Ferrera, A.Sharma, I.Milekhin, Y.Pan, D.Convertino, S.Pace, G.Orlandini, E.Peci, L.Ramò, M.Magnozzi, C.Coletti, G.Salvan, D.R.T.Zahn, M.Canepa, F.Bisio, *Local dielectric function of hBN-encapsulated WS_2 flakes grown by chemical vapor deposition.* Journal of Physics: Condensed Matter, 2023, 35.27: 274001

In preparation:

L.Ramò, E.Peci, M.C. Giordano, P.Canepa, F.B. de Mongeot, M.Canepa, F.Bisio, *Non-invasive deterministic plasmonic nanostructures lithography on 2D transition metal dichalcogenides.*

N.Petrini, E.Peci, et al., *Optimizing Gold-Assisted Exfoliation of Layered Materials with (3-Aminopropyl)triethoxysilane (APTES): A Promising Approach for Large-Area Monolayers.*

P.Canepa, E.Peci, et al., *Surface Patterns on CVD-Grown Monolayer WS_2 Flakes: an investigation with AFM Adhesion and Friction signals.*

PH.D. COURSES

Nanophotonics and nanofabrication (Dr. M.C.Giordano)

Optoelectronics of nanomaterials (Dr. I.Kriegel, Dr. D.Baranov, Dr. F.Di Stasio) – exam passed

TEACHING ACTIVITY

Teaching assistant (60 hours) for the "General Physics" course (Prof. Enzo Franco Branchini and Prof. Guido Gagliardi), B.Sc. in Biomedical Engineering, Università di Genova. Exercises at the blackboard (mechanics, thermodynamics, electromagnetism) and tutoring activity.

Invited seminar (1 hour) on "*2D Transition Metal Dichalcogenides"* for the M.Sc. course "*Spectroscopies and Materials for Photonics"* (Prof. M.Canepa and Dr. F.Bisio), Università di Genova.

Assistance for high school students visiting the Physics Department: lab demonstration about the properties of different light sources.