RELAZIONE ATTIVITA’ ANNUALE DEI PERFEZIONANDI/DOTTORANDI – SECONDO ANNO

REPORT ON THE PHD ACTIVITY – SECOND YEAR

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| **NOME E COGNOME**  **NAME AND SURNAME** | Giulia Piccinini |
| **DISCIPLINA/PHD COURSE** | Nanosciences |

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| **CORSI FREQUENTATI CON SOSTENIMENTO DI ESAME FINALE**  **ATTENDED COURSES (WITH FINAL EXAM)** | **VOTAZIONE RIPORTATA**  **MARK** | **NUMERO DI ORE**  **HOURS** |
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| **CORSI FREQUENTATI SENZA SOSTENIMENTO DI ESAME FINALE**  **ATTENDED COURSES (ATTENDANCE ONLY)** | **NUMERO DI ORE**  **HOURS** |
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| **ALTRE ATTIVITÀ FORMATIVE (SEMINARI, WORKSHOP, SCUOLE ESTIVE, ECC.) – DESCRIZIONE**  **OTHER PHD ORIENTED ACTIVITIES (SEMINARS, WORKSHOPS, SUMMER SCHOOLS, ETC) – DESCRIPTION** | **NUMERO DI ORE**  **HOURS** |
| Graphene Flagship's WP3 annual meeting – Active participation. Talk title: “Deterministic direct growth of WS2 on CVD graphene arrays**”** | 20 |
| Webinar – Python Base (Luca Coviello) | 6 |
| Webinar – Relevant Performance Parameters for professional EBL: About Truth and Myth | 1 |
| Webinar – Nanocontacting and Device Fabrication of randomly distributed 1D and 2D materials | 1 |
| [2020 Joint Conference of the Condensed Matter Divisions of EPS (CMD) and RSEF (GEFES)](https://eventos.uam.es/event_detail/28512/detail/2020-joint-conference-of-the-condensed-matter-divisions-of-eps-cmd-and-rsef-gefes.html) | 7 |

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| **ATTIVITÀ DI RICERCA EVENTUALMENTE SVOLTA (MAX. 8.000 CARATTERI)**  **RESEARCH ACTIVITY (MAX. 8000 CHARACTERS)** |
| During my PhD, I focused my activities on the study of structural and electrical properties of van der Waals heterostructures.  **1) Tungsten disulfide(WS2)/graphene heterostructures**  Last year I worked on the WS2/graphene heterostructure, an interesting assembly for optoelectronic and spintronic applications. I performed the direct synthesis of monolayer WS2 on single-crystal CVD (chemical vapor deposition) graphene arrays and I characterized such heterostack. The growth of WS2 on graphene is selective, a clear advantage for the fabrication of devices, since the vertical heterostructure is deterministically obtained in arrays without the need of any top-down post-processing. Electrical transport measurements proved that the heterostructure behaves like an electron-blocking layer, which might be suitable for the development of unipolar components in optoelectronics. These results were published at the beginning of the past academic year1.  Following this activity on WS2/graphene heterostructures, further research was performed in collaboration with several collegues. Specifically, Fabbri et al. studied the aging of WS2 on graphene, while its complex dielectric function was investigated with spectroscopic ellipsometry (SE) in collaboration with people at Università degli Studi di Genova.  **2) Twisted bilayer graphene encapsulated in hexagonal boron nitride (hBN)**  During my second year of PhD, I studied another appealing van der Waals heterostructure, which is hBN/twisted bilayer graphene/hBN. In recent years there has been an increasing interest in bilayer graphene, in particular for the case of the two graphene layers twisted one with respect to the other. Indeed, the twist angle between adjacent layers of graphene provides an exotic degree of freedom to enable various fascinating phenomena. Moreover, the presence of bottom and top layers of hBN allows to change the charge density in the two graphene sheet with a fine-grained control. In order to make devices for magnetoelectric measurements in this type of structures, I developed characterization and fabrication skills. As a matter of fact, once the heterostructure is assembled, Raman spectroscopy is fundamental for two reason: first, to check if the twist angle between the graphene layers is the desired one; second, to select the best possible area for device fabrication. Then, it is necessary to scan such area with an Atomic Force Microscope (AFM), in order to assess the cleanliness and flatness of that region. Indeed, the presence of air bubbles embedded in the heterostack is detrimental, since it prevents to reach high mobilities and homogeneous twist angles. During this year I fabricated Hall bars and constrictions, with top and bottom gates. I focused on optimizing the fabrication of edge contacts in such heterostructures.   * I started working on **hBN/30°-twisted bilayer graphene/hBN** heterostructures. The twisted bilayer graphene (tBLG) was synthesized via CVD, eliminating the need of manual assembly. Then, the tBLG was embedded between two hBN flakes, and Hall bar devices for magnetotransport measurements in a double-gate configuration were fabricated (Fig. 1a). The devices exhibited carrier mobilities up to 105 cm2/Vs and low-temperature magnetotransport measurements showed that the large twist angle in tBLG makes it behave as two uncoupled graphene layers, presenting 8-fold degenerate quantum Hall states (Fig. 1b)2. Being the two graphene sheets decoupled, by acting on the two gates, it is possible to control the charge densities of the upper and lower layer independently. For example, it is feasible to completely empty one layer and to transfer the whole charge on the other one. The development of an electrostatic model enabled me to obtain the charge density of each graphene layer in 30°-tBLG and to plot it as a function of the top and bottom gate voltages. Thus, for every couple of top and bottom gate voltage values we can determine the Fermi energy and the charge density for both layers, as well as the displacement field between the two. We found this model to be in agreement with our last results on hBN/30°-tBG/hBN, with the calculated charge neutrality points (CNP) of the two graphene layers following the experimental data (Fig. 1c). * Currently, I am working on a manual stacking of two CVD graphene layers with a twist angle of 1.1°, encapsulated in hBN. For such angle, which in the literature is referred to as ‘magic’, the electronic band structure of tBLG exhibits flat bands near zero Fermi energy, resulting in correlated insulating states at half-filling. This was observed experimentally using exfoliated graphene3. My goal is to perform the same measurements with CVD graphene. After having assembled an **hBN/1.1°-tBLG/hBN** stack that showed a promising Raman spectrum, I fabricated a Hall bar device. Magnetotransport measurements will be performed in the next weeks.     **Figure 1.** a) Optical image of a Hall bar on hBN/30°-tBLG/hBN. b) Hall conductivity as a function of carrier density at *B* = 1 T, for *D* = 0 (red line) and D >> 0 (blue line). The inset shows a schematic cross section of the devices studied (light grey = Si; dark grey = SiO2; black = graphene; dark cyan = hBN; yellow = Cr/Au). c) Derivative of the resistivity as a function of the gate voltages at *B* = 0 around the CNP. CNP for the upper (black) and lower (red) layers calculated using the electrostatic model.  **References**  (1) G. Piccinini *et al.*, *2D Mater*., **7**, 014002 (2019)  (2) S. Pezzini *et al.*, *Nano Letters*, **20**, 3313−3319 (2020)  (3) Y. Cao *et al.,* [*Nature*](https://www.nature.com/nature),**556**, 43–50 (2018) |

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| **EVENTUALI PUBBLICAZIONI**  **PUBLICATIONS (IF AVAILABLE)** |
| * G. Piccinini *et al.*, Deterministic direct growth of WS2 on CVD graphene arrays, *2D Mater.*, **7**, 014002 (2019) * M. Magnozzi *et al.*, Optical dielectric function of two-dimensional WS2 on epitaxial graphene, *2D Mater.*, **7**, 025024 (2020) * S. Pezzini *et al.*, 30°-twisted bilayer graphene quasicrystals from chemical vapor deposition, *Nano Letters*, **20**, 3313−3319 (2020) * F. Fabbri *et al.*, Edge defects promoted oxidation of monolayer WS2 synthetized on epitaxial graphene, *J. Phys. Chem. C*, **124**, 16, 9035–9044 (2020) * V. Miseikis *et al*., Ultrafast, zero-bias, graphene photodetectors with polymeric gate dielectric on passive photonic waveguides, *ACS Nano*, **14**, 11190–11204 (2020) |

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| **NOME DEL RELATORE**  **THESIS ADVISOR** |
| Dr. Camilla Coletti |

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| **DATA**  **DATE** | 18/10/2020 | **FIRMA**  **SIGNATURE** |  |