FIRST YEAR PhD REPORT

Student: Matteo Gardella

Tutors: Francesco Buatier de Mongeot, Marina Giordano

RESEARCH ACTIVITY

During the first year of my PhD I have been working on the foundations of my research project, with the final aim of increasing optical absorption and photoconduction in large area nanostructured 2-dimensional semiconductors ultra-thin films, i.e. thickness in the range of few nanometers (from a monolayer to few monolayers). To achieve this result, the idea is to exploit substrate nanostructuring (light trapping and diffractive effects) as a functional template for the growth of 2D materials heterostructures (e.g. adding graphene as transparent electrode). A further degree of freedom for the optical manipulation is the integration of plasmonic nanostructures (e.g. hot electrons injection into 2D active material).

Among 2D semiconductors MoS_2 has been largely studied in the form of exfoliated single crystal flakes, but this approach has the major drawback of producing flakes with dimensions in the size of few microns. The limited area makes it difficult to use this material for practical applications, e.g. devices, because it requires the use of expensive and time-consuming lithographic techniques. A new approach arising in the last years is that of large area CVD synthesis techniques, allowing to overcome the size limitation of mechanical exfoliation. Regarding my personal activity, so far the large area MoS_2 films I have been working on have been grown in collaboration with Agrate-Brianza CNR-IMM. While continuing the characterization of samples realized in collaboration with CNR, I am also working on the realization of an experimental set-up, based on a single zone tubular oven, that will allow in-house samples preparation through sulphurization of pre-deposited molybdenum ultra-thin films (few layer thickness).

Despite the MoS_2 excellent optical absorption coefficient, the effective absorption is poor due to the reduced thickness of the MoS_2 films, thus requiring for innovative strategies to increase efficiency. For this reason, the first approach we have been exploring is that of dielectric substrates nanostructuring. Recurring to an optical lithographic technique (Laser Interference Lithography, LIL) and successive transfer of the polymeric mask geometry to the silica substrate (through Reactive Ion Etching, RIE) we have been able to achieve large area nanostructured substrates with one-dimensional subwavelength periodicity. This configuration allows both for a reduction in reflection due to Moth-eye effect, resulting in an increased light-material interaction when MoS_2 is grown on such a substrate, and for diffractive effects due to the periodicity, resulting in a larger optical thickness of the MoS_2 film.

Still concerning the nanofabrication process, I am working on a controlled modification of the gratings morphology through Ion Beam Sputtering (IBS). The initial morphology is symmetric due to the geometry of the silica etching process. The capability to control the grating profile (the local curvature, slope and amplitude in particular) is very important for the study of the so called ‘strain engineering’, i.e. the controlled modification of the material properties caused by the mechanical distortion of the crystal lattice (in this case due to conformal growth on the grating). So far these gratings have only been sputtered at normal incidence in order to round up the ridges and flatten the valleys. Recently I have started experiments which aim at modifying the profile of the grating by sputtering at a different incident angle, aiming at the formation of blazed silica gratings in analogy to faceted glass samples obtained by self-organization under sputtering, but with the advantage of large area regularity. Future experiments will also explore the possibility to finely tailor the morphology of the slanted grating by acting on other parameters of the ion beam (ion dose, ion energy, ion species).

On a long term perspective I have also started working on a wet transfer process of large area CVD commercial graphene (monolayer and bilayer). This will be useful for the realization of 2D-materials heterostructures and devices. Thanks to its properties, graphene can serve as transparent electrode in such devices. First transfer trials have proven encouraging results regarding the flatness and continuity of the transferred graphene layer. An interesting follow-up that I am starting to work on is the transfer of graphene flakes on nanostructured substrates like silica gratings or self-organized rippled glasses, aiming to induce some form of corrugation into the graphene layer and evaluating possible modifications in graphene properties.

ATTENDED COURSES

- “Organic materials for photonics” (Comoretto), exam in preparation
- “Fondamenti di microscopia elettronica a scansione ed in trasmissione” (Riani), exam passed
- “Tecniche microscopiche e spettroscopiche per superfici e interfacce” (Buzio-Gerbi-Savio) POSTPONED DUE TO COVID EMERGENCY
- “Nanofluidics” (Siria) CANCELLED? DUE TO COVID EMERGENCY
- Additional course not originally scheduled: Nano Frazor webinar series by Heidelberg Instruments (around 15 hours)

PUBLICATIONS

Manuscript under submission:

“Broadband and tunable light harvesting in nanogrooved MoS_2 ultra-thin films”, Mukul Bhatnagar, Matteo Gardella

CONFERENCE PRESENTATIONS

None