SECOND YEAR PhD REPORT

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RESEARCH ACTIVITY

The second year of my PhD project has been mostly dedicated to optimizing the growth of 2D Transition Metal Dichalcogenides (MoS_2 and WS_2) and to the fabrication of van der Waals heterostructures (MoS_2-WS_2 or MoS_2-graphene).

After having completed the experimental set-up that now allows for the in-house sulfurization of Transition Metal Dichalcogenides, I initially worked on large area growth of MoS_2 ultra-thin films (few nanometers) by sulfurization of solid MoO_x precursor films deposited via RF-sputtering of a molybdenum target. The sulfurization success has been verified by optical and Raman characterization, both showing the typical MoS_2 features.
However, the growth process is complicated by the partial sublimation of the MoO_x precursor film prior to sulfurization, especially when decreasing the thickness to the very ultimate thickness (2-3 nm). For this reason, I studied an alternative process based on MoS_x precursor films deposited via RF-sputtering of a MoS_2 target directly. In this way, the reduced oxidation due to the partial saturation of Mo-S bounds in the precursor film results in a better control of the sulfurization process, allowing for an easy sulfurization of MoS_2 films as thin as 2-3 nm.
In the case of conventional RF-sputtering the deposition flux has a very high angular spread: while this is not a problem for film deposition on flat substrates, it becomes crucial in case of shadow deposition of nanostructures at grazing incidence on relief patterns. For this reason, I developed and tested a new instrumental prototype that enables precursor films deposition via ion beam sputtering of the target (either metallic molybdenum or MoS_2). The manipulator of such prototype allows for tilting the sample to control the deposition incidence angle. Thanks to the reduction of source divergence and the control on deposition angle, deposition of laterally disconnected facets on nanostructured substrates is now possible.

During this year I also started working on WS_2 growth. Even in this case the process consists in the initial deposition of a precursor film via ion beam sputtering (either of tungsten or WS_2 target) and subsequent sulfurization. Sulfurization with the same parameters adopted for MoS_2 growth has given encouraging results, as demonstrated again by optical and Raman characterization. Combined with the previously mentioned possibility to deposit facets on nanostructured substrates, this sulfurization process compatibility is crucial for the future growth of 2D materials stacked to form van der

Waals heterostructures. First preliminary samples (planar stacks and deposition at controlled angle on grating substrates) are under fabrication.

In parallel with MoS_2 and WS_2 growth I kept working on the wet transfer of commercial large area graphene. First flat graphene samples have been used as transparent electrodes for the growth of MoS_2, that has proven to be successful. Although the MoS_2 films on graphene show vertical conductivity due to nanometric thickness (though the measured resistance is dominated by graphene resistance), the future aim will be to improve the MoS_2 in-plane conductivity. For this reason, we have started preliminary experiments of MoS_2 electron beam irradiation trying to induce atomic rearrangement on the nanoscale.
In addition to transfer of planar graphene, I also prepared first samples of free-standing graphene by transfer on a silica grating that could be used either as graphene-based pressure sensors (preliminary experiments going on) or as a platform for the growth of periodically corrugated heterostructures graphene-MoS_2 (characterization of a preliminary sample going on).

ATTENDED COURSES

- "Biosensing" (Angeli, Cavalleri), exam passed
- "Introduction to nanophotonics and nanofabrication" (Giordano), exam in preparation
- "Tecniche microscopiche e spettroscopiche per superfici e interfacce" (Buzio-Gerbi-Savio), exam in preparation

EXAMS GIVEN

- "Organic materials for photonics" (Comoretto)
- Presentation on Nano Frazor webinar series by Heidelberg Instruments

PUBLICATIONS

- M. Bhatnagar, M. Gardella *et al.*, "Broadband and tunable light harvesting in nanorippled MoS_2 ultrathin films", *ACS Appl. Mater. Interfaces* 2021, 13, 11, 13508–13516

CONFERENCE PRESENTATIONS

- Photonics Online Meetup 2021, poster contribution
- Semiconductor and Integrated Opto-Electronics Conference 2021, oral contribution
- Joint EPS-SIF International School on Energy 2021, student talk (awarded with a distinction)
- Micro and Nano Engineering Conference 2021, poster contribution
- European Materials Research Society 2021 Fall Meeting, oral contribution