Electrical properties of large single-crystal tungsten disulfide grown by liquid precursor chemical vapor deposition

Leonardo Martini[1]
Niccolò Martinolli[3], Paolo Paletti[1,2], Domenica Convertino[1,2], Giorgio Orlandini[4], Hasret Agircam[1,5], Simona Pace[1,2], Stiven Forti[1], Vaidas Miseikis[1,2], Camilla Coletti[1,2]

1. Center for Nanotechnology Innovation @ NEST, Istituto Italiano di Tecnologia, Piazza San Silvestro 12, 56127, Pisa, Italy
2. Graphene Labs, Istituto italiano di tecnologia, Via Morego 30, I-16163 Genova, Italy
3. Department of Civil and Industrial Engineering, University of Pisa, Largo Lazzarino 1, Pisa, 56122, Italy
4. Department of Condensed Matter Physics, University of Pisa, Largo Bruno Pontecorvo 3, 56127 Pisa, Italy
5. Department of Metallurgical & Materials Engineering Istanbul Technical University, 34469 Maslak, Istanbul, Turkey

leonardo.martini@iit.it

The research in two-dimensional (2D) materials has attracted great interest in recent years, for electronic, spintronic and optoelectronics applications. One class of 2D materials of particular interest are transition metal dichalcogenides (TMDs), where one layer of transition metal atoms is packed between two layers of dichalcogenide atoms[1]. One of the most interesting properties of this class of material is the presence of a bandgap, which changes from indirect to direct when the thickness goes from bulk to monolayer[2].
One of the most promising TMDs is tungsten disulfide(WS_2)[3], due to the presence of a direct bandgap in the visible range (around 2 eV) that makes it suitable for electronics and optoelectronics applications. Hence, controlling the growth process in order to obtain highly crystalline WS_2 with appreciable electronic and optical properties is of primary importance.
Here we report on the growth, through liquid-phase chemical vapor deposition (LiP-CVD)[4], of monolayer single-crystal WS_2 on Silicon dioxide, with lateral size up to hundreds of micrometers.
The quality of the grown material is assessed through atomic force microscopy (AFM), Raman and photoluminescence spectroscopy, which confirm the single-crystal and monolayer nature of our samples. The electrical properties of LiP-CVD WS_2 are tested with transport measurements. To this end, Transfer Length Measurement (TLM) devices are defined via electron beam lithography (EBL), thermal metal evaporation and reactive ion etching (RIE). We demonstrate field-effect mobilities above 15 cm^2/Vs and an on/off ratio in the range of 10^6. Moreover, we also test the electrical photo-responsivity of the material, proving a wavelength-dependent photocurrent of hundreds of microampere and a photoresponsivity as high as 10 A/W.

Acknowledgment

This work has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement 881603.

References

[1] R. G. Dickinson and L. Pauling, "The crystal structure of molybdenite," *J. Am. Chem. Soc.*, vol. 45, no. 6, pp. 1466–1471, Jun. 1923.
[2] C. Cong, J. Shang, Y. Wang, and T. Yu, "Optical Properties of 2D Semiconductor WS 2," *Adv. Opt. Mater.*, vol. 6, no. 1, p. 1700767, Jan. 2018.
[3] S. Ulstrup *et al.*, "Spin and valley control of free carriers in single-layer WS 2," *RAPID Commun. Phys. Rev. B*, vol. 95, no. R, p. 41405, 2017.
[4] H. Y. Jeong *et al.*, "Heterogeneous Defect Domains in Single-Crystalline Hexagonal

WS2," *Adv. Mater.*, vol. 29, no. 15, Apr. 2017.

Figures

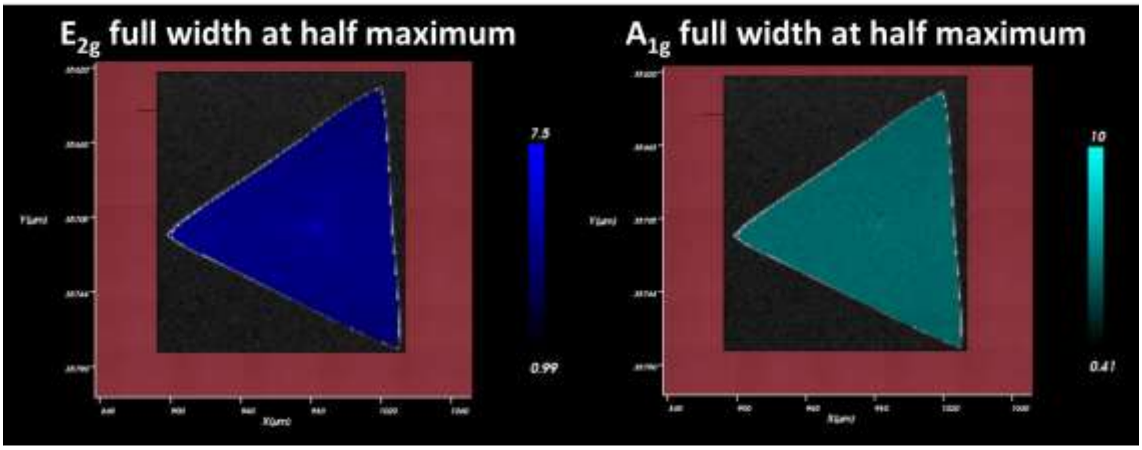

Figure 1: Raman characterization of a LiP-CVD grown WS_2 crystal: On the left, the map of the $FWHM(E_{2g})$ peak shows homogeneity of the strain on the sample and the high quality of the synthesized material. On the right, the map of the $FWHM(A_{1g})$ peak demonstrates high level of homogeneity of the sample. Raman characterization has been performed with laser excitation of 473 nm, 1.4 mW of power, the measurements were performed with a 100x (0.89 NA) magnification lens, that produces a spot size of 0,7 µm.

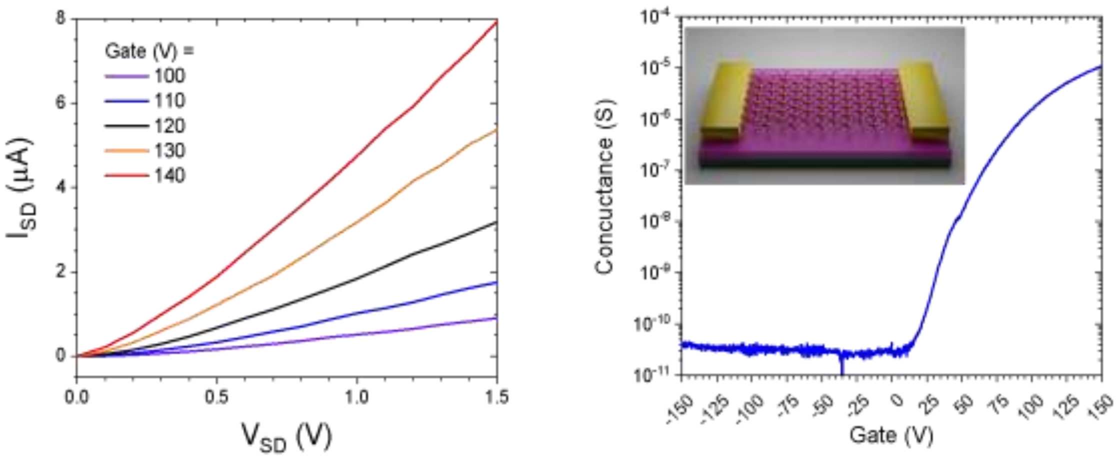

Figure 2: Electrical characterization of the WS_2-based FET device: On the left, the output characteristic of a device demonstrates current in the order of tens of µA; the super-linear onset for applied biases below 0.5 V suggests the presence of a contact-limited transport. On the right, a transfer curve in a semi-log scale, WS_2 FET device show a n-type behavior, with an on/off ratio above 10^5 and onset voltage around 20 V (over 285 nm of SiO_2); we obtained FET mobility of 15 cm^2/Vs.