Charge transport in Graphene-P3HT blends studied by Kelvin Probe Force Microscopy and FET characterizations

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OS- based devices

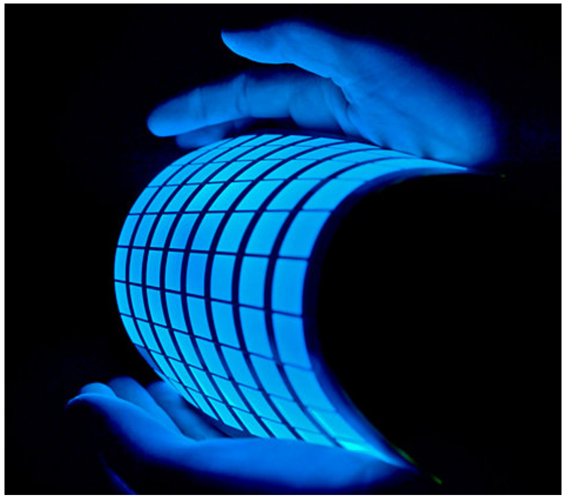
Organic semiconductors (OS) based electronic devices (OFET, LEDs, RFID, solar cells, …) are competitive for some focused applications, where the main issues are:

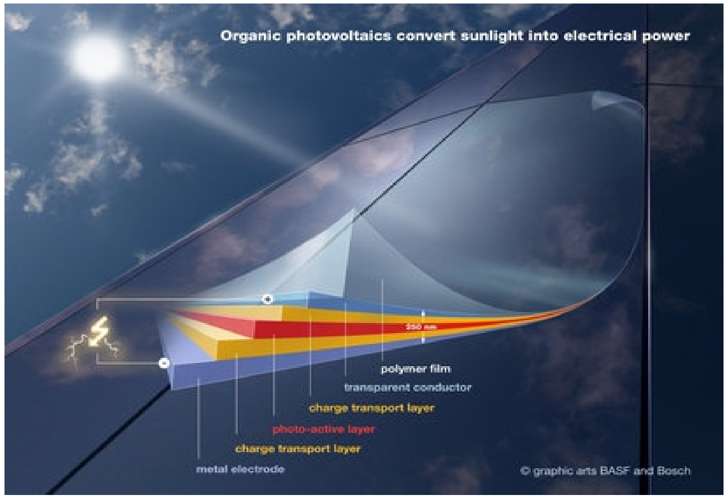
- Low cost
- Low weight
- Flexible electronics

Main limitation → low effective mobility

$$\Delta t_{Switching} \propto \frac{L^2}{V \times \mu_{eff}}$$

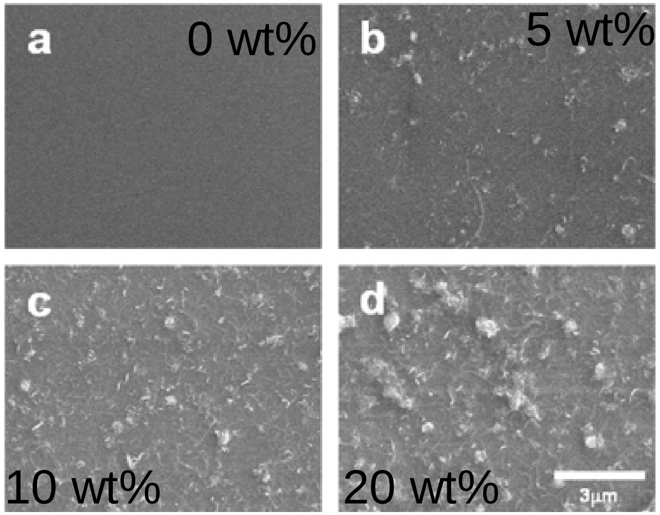
SLOW ELECTRONICS

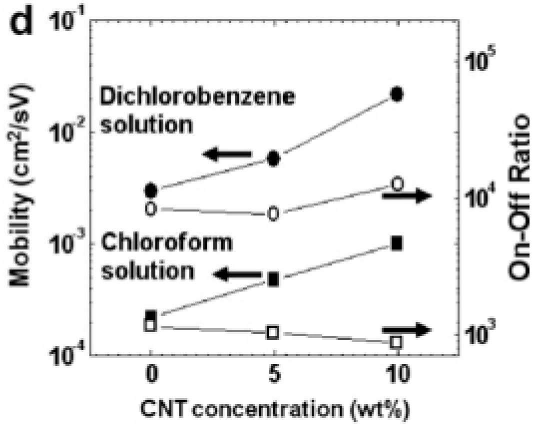




C - enhanced OS based electronics

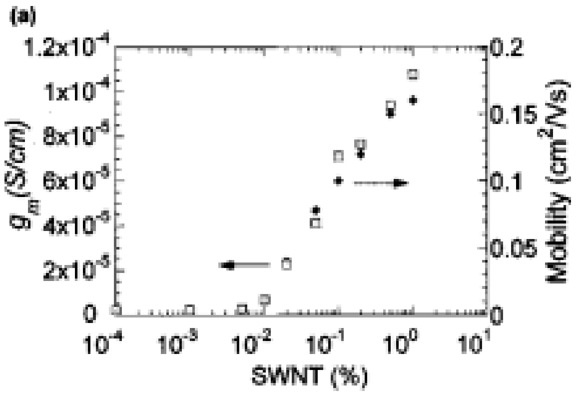
Proposed solutions to improve OFET performances (mainly mobility) make use of CNT/OS blends

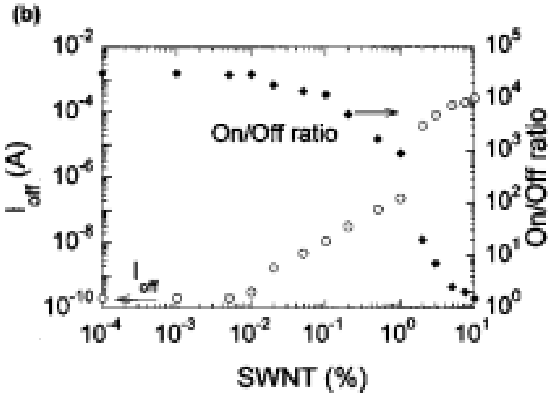




CNT/P3HT

Y.D. Park et al. Organic Electronics 9 (2008) 317





.Z. Bo et al. APL 86 (2005) 182102

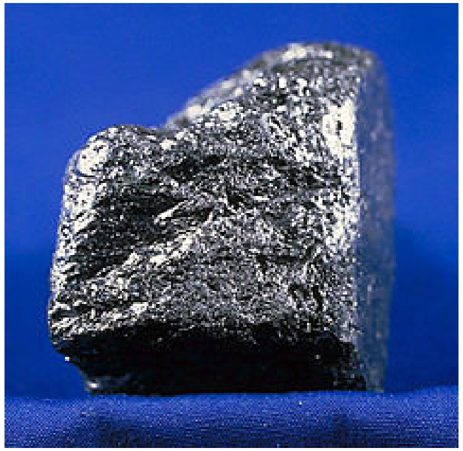
Our approach: CNT/OS blends → Graphene/OS blends

Graphene-s

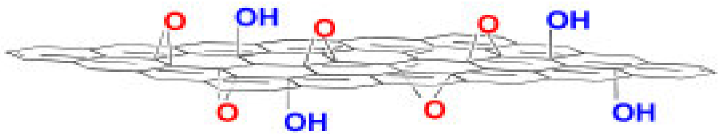
Graphene can be produced with different methods:

- Mechanically exfoliation (easy and low cost, but serendipitous)
- Epitaxial growth from SiC (large scale but high temperatures)
- C-CVD growth (large scale but high temperatures)
- Exfoliation of graphite in solvents (easy to process but low yield)
- **Graphene oxide $\longrightarrow$ reduced graphene oxide (large scale achievable and easy to process but structural disorder)**

Graphene Oxide preparation



Modified Hummers Method



Graphene Oxide (GO)

E. Treossi et al. JACS 131 (2009), 15576

Chemical reduction

($NaBH_4$, H_4N_2,…)

or

Thermal reduction

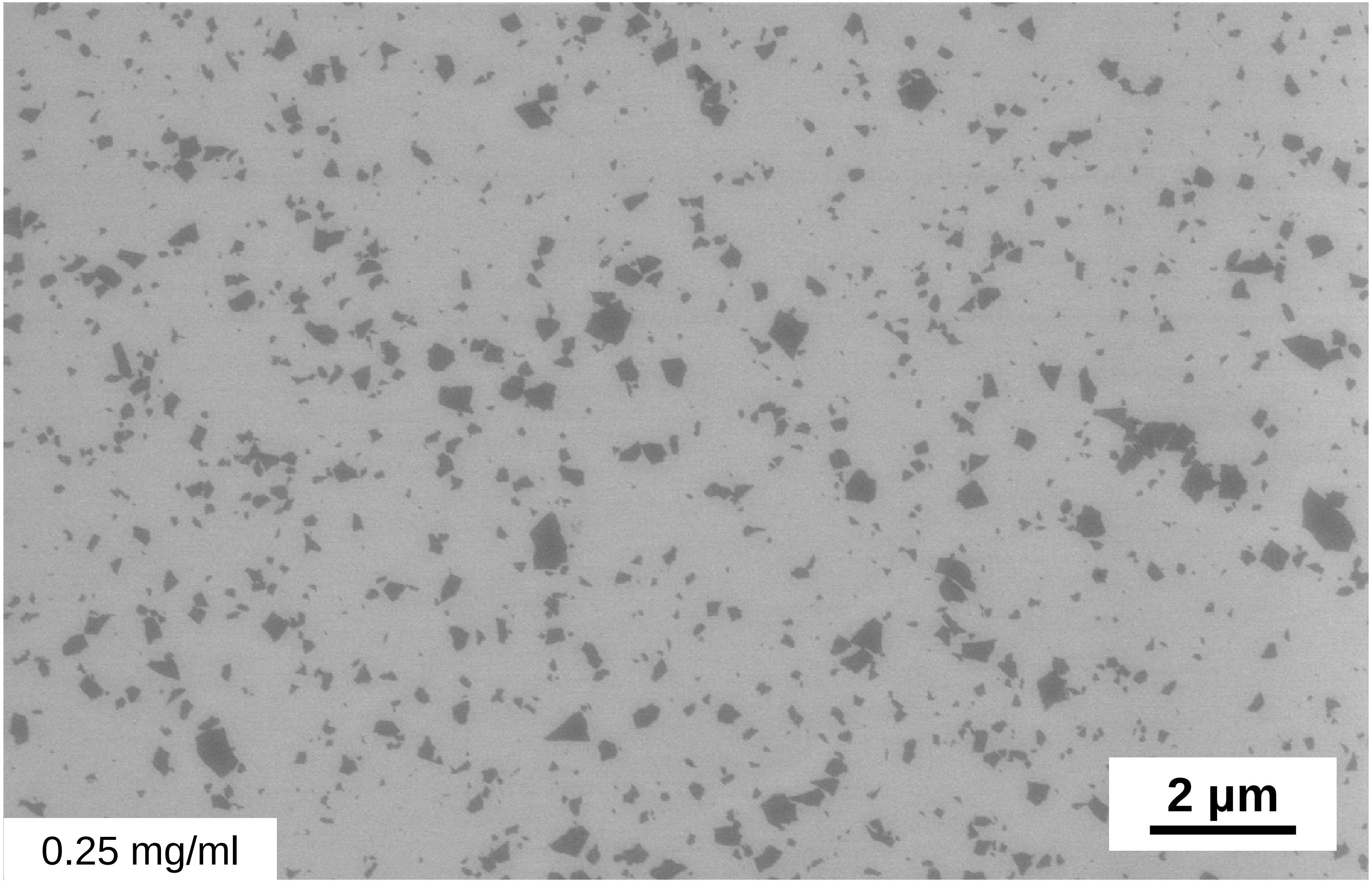
Controlling sonication time and concentration it is possible to tune:

- **sheet size (0.3 ÷ 300 μm)**
- **substrate coverage**

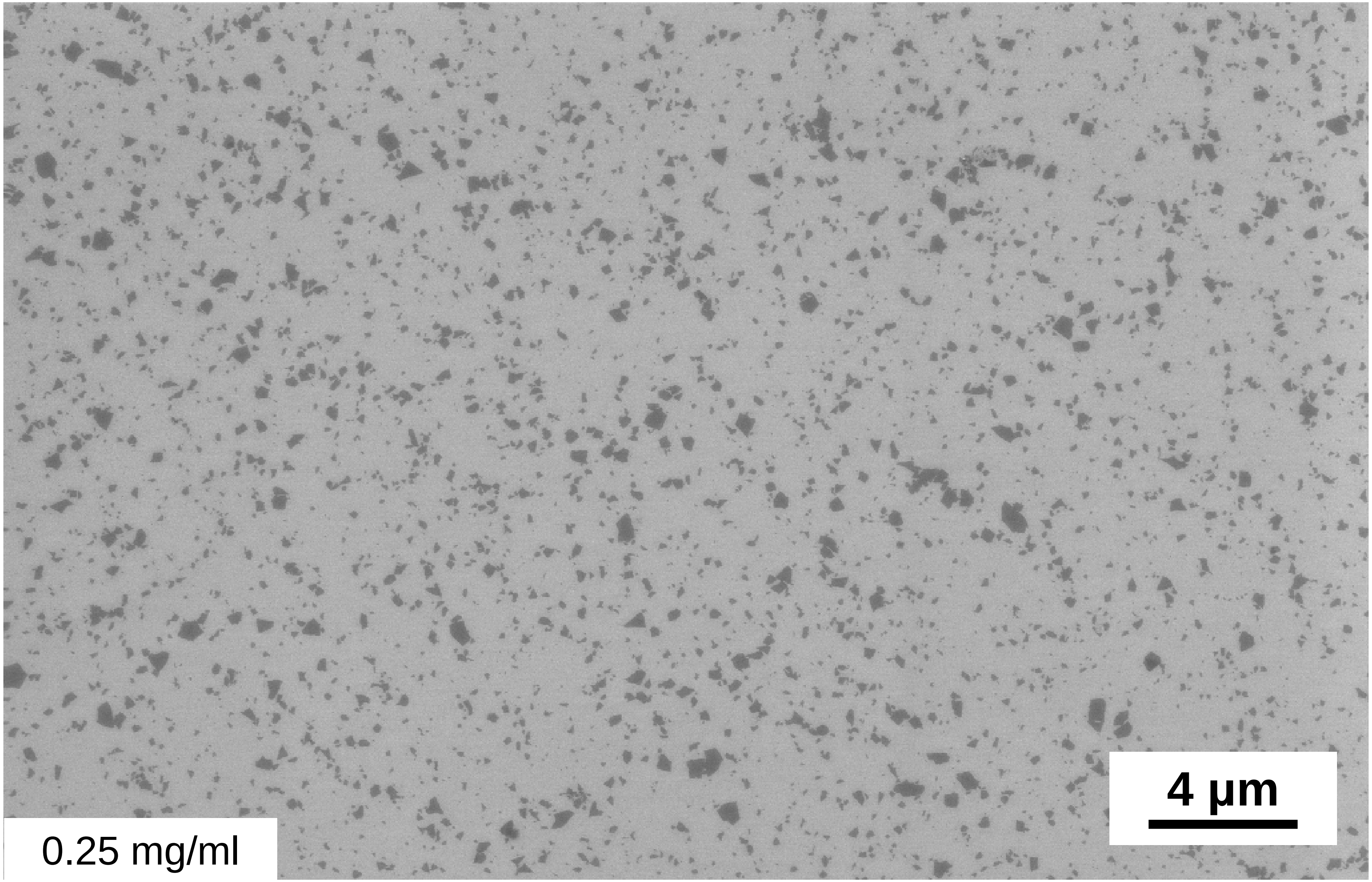
Reduced Graphene Oxide (RGO)

C. Mattevi et al., Adv. Funct. Mater. 19 (2009), 2577

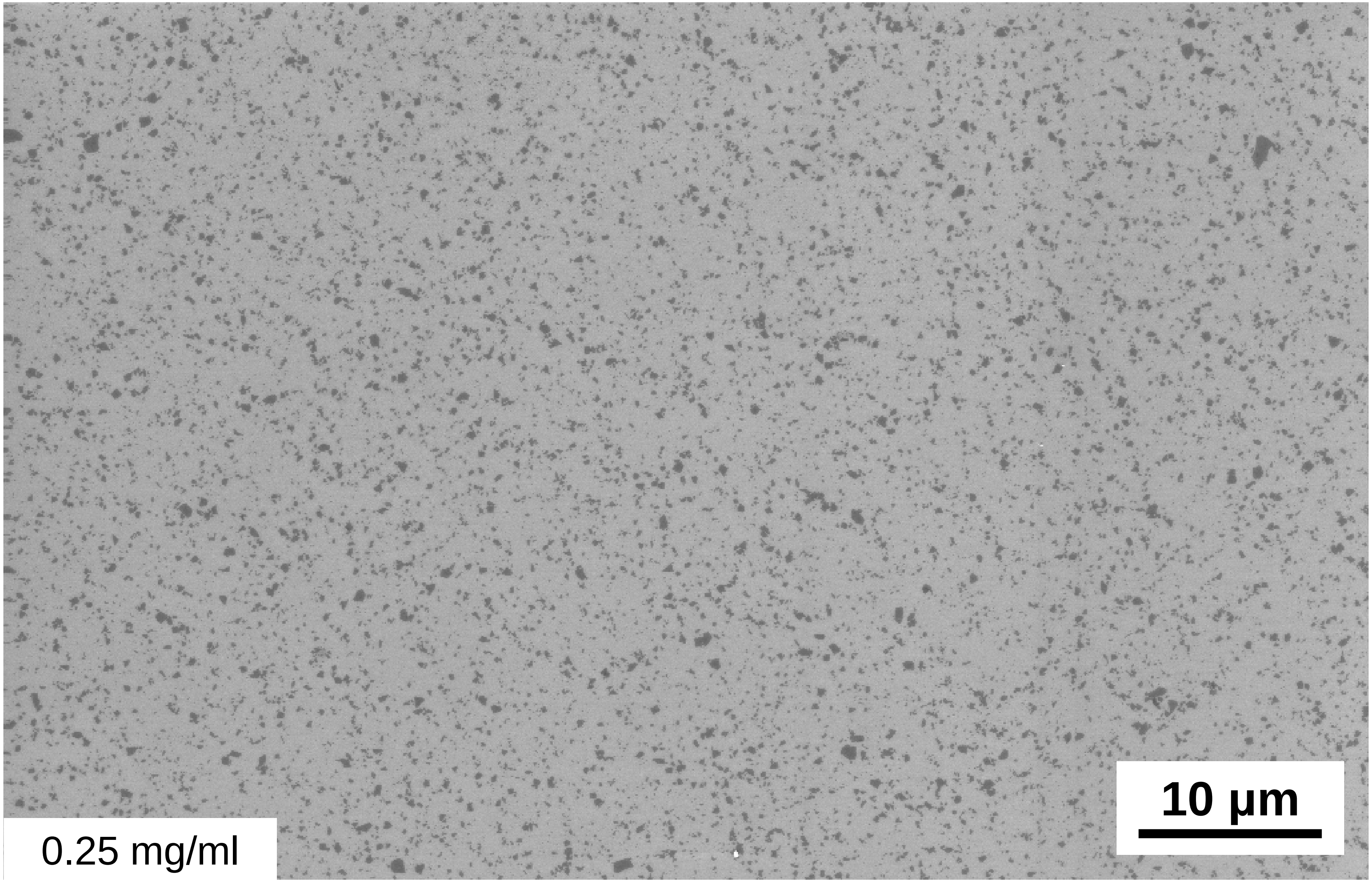
GO deposition by spin coating on SiO_2



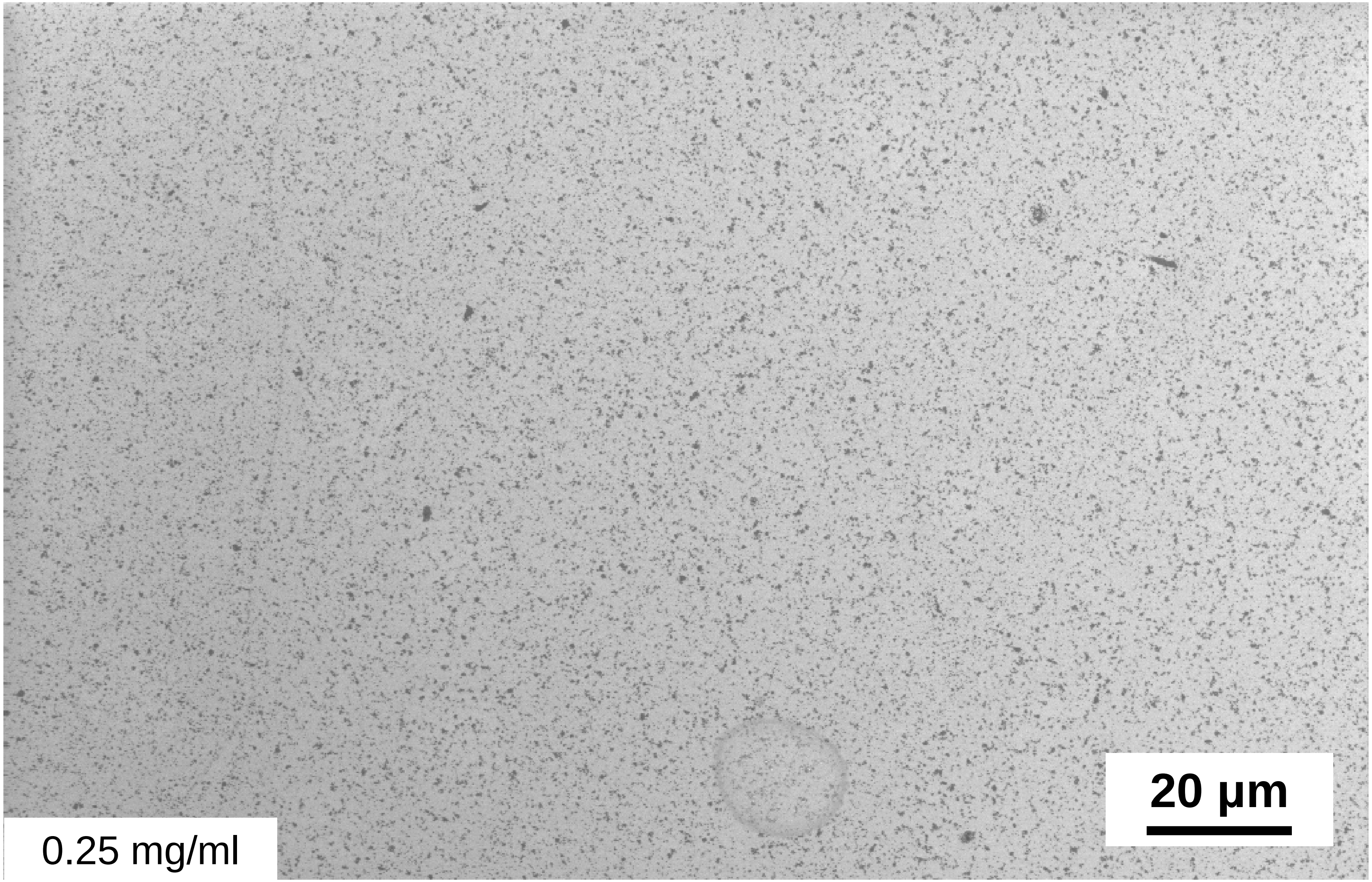
GO deposition by spin coating



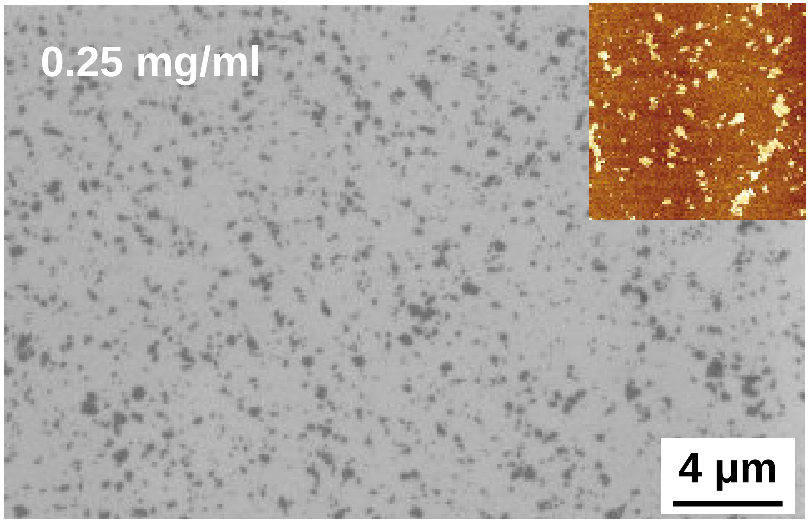
GO deposition by spin coating

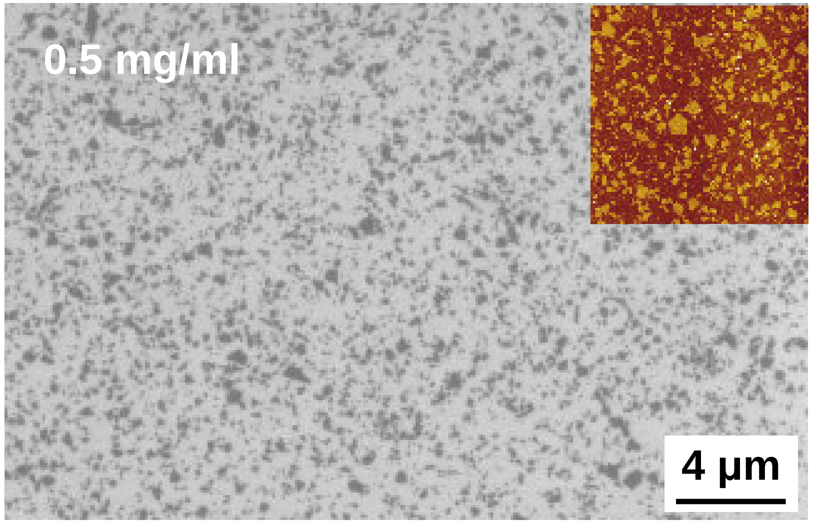


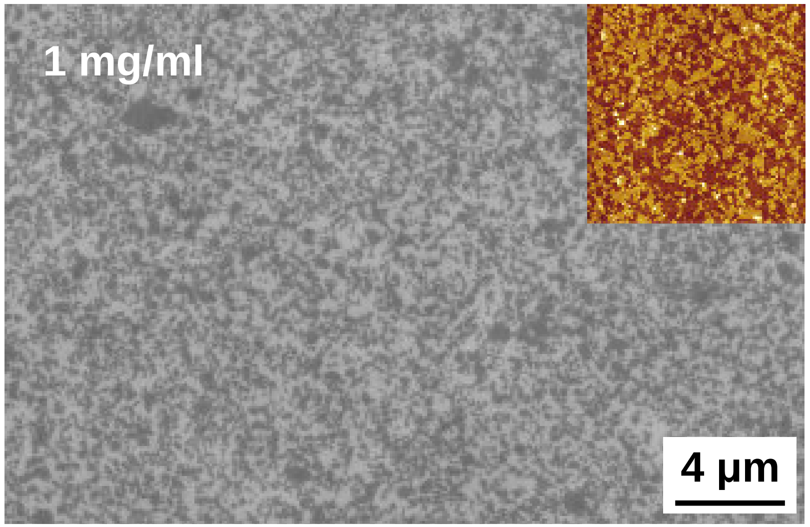
GO deposition by spin coating

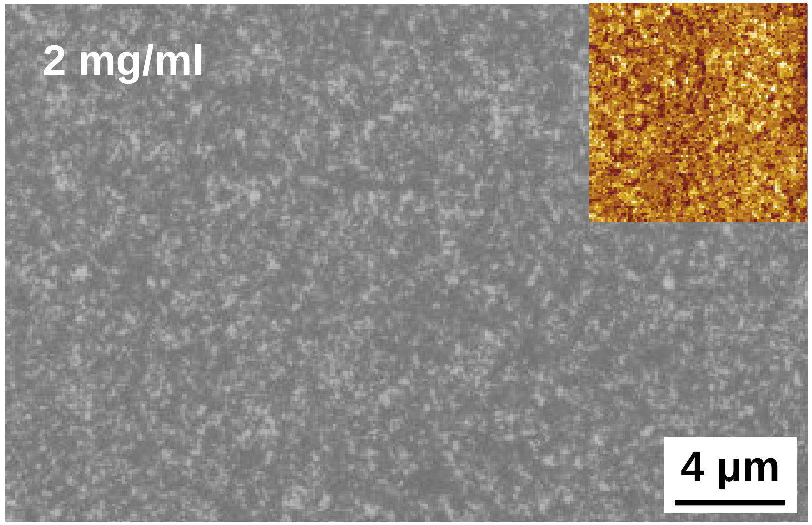


GO deposition

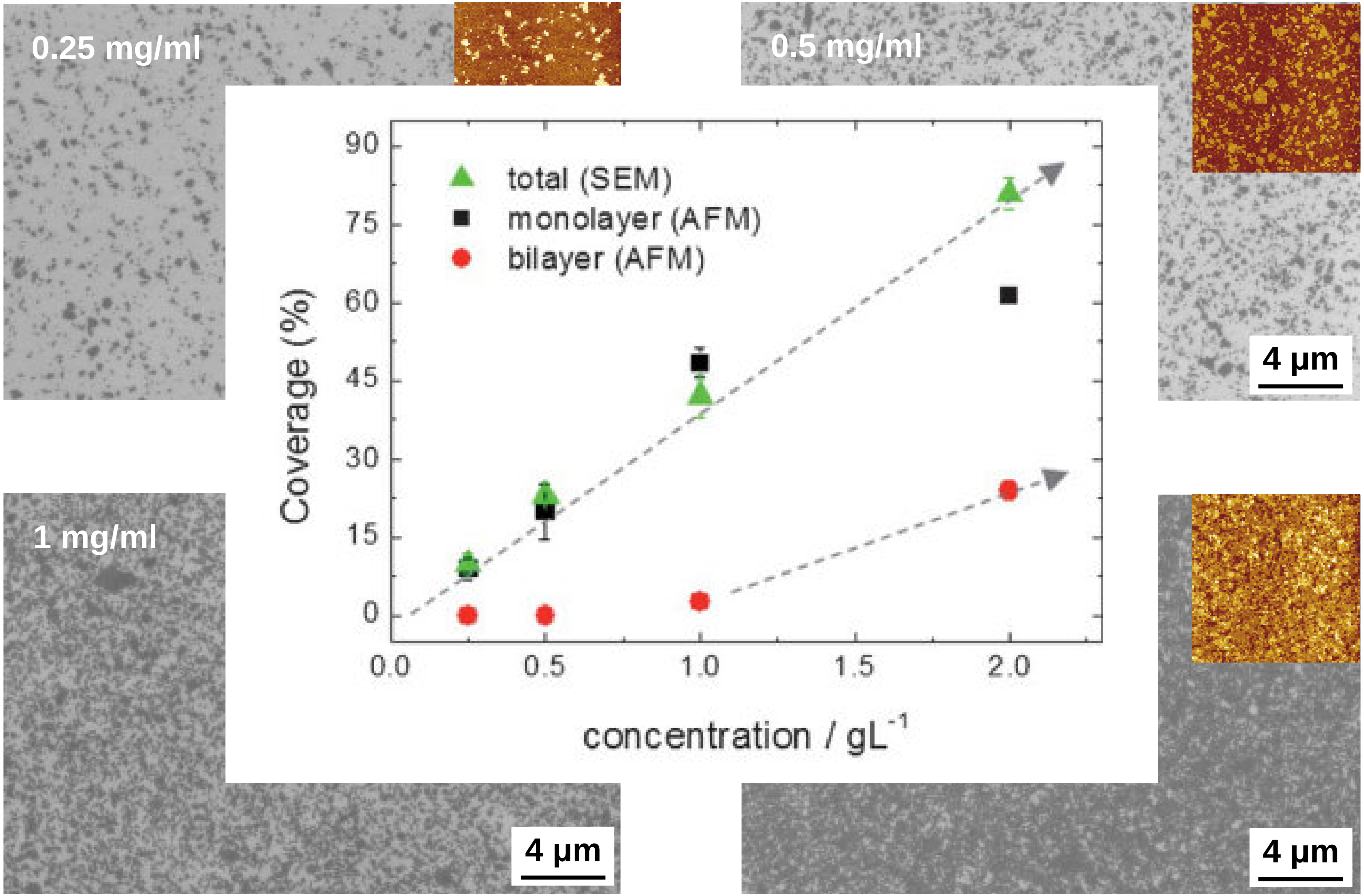






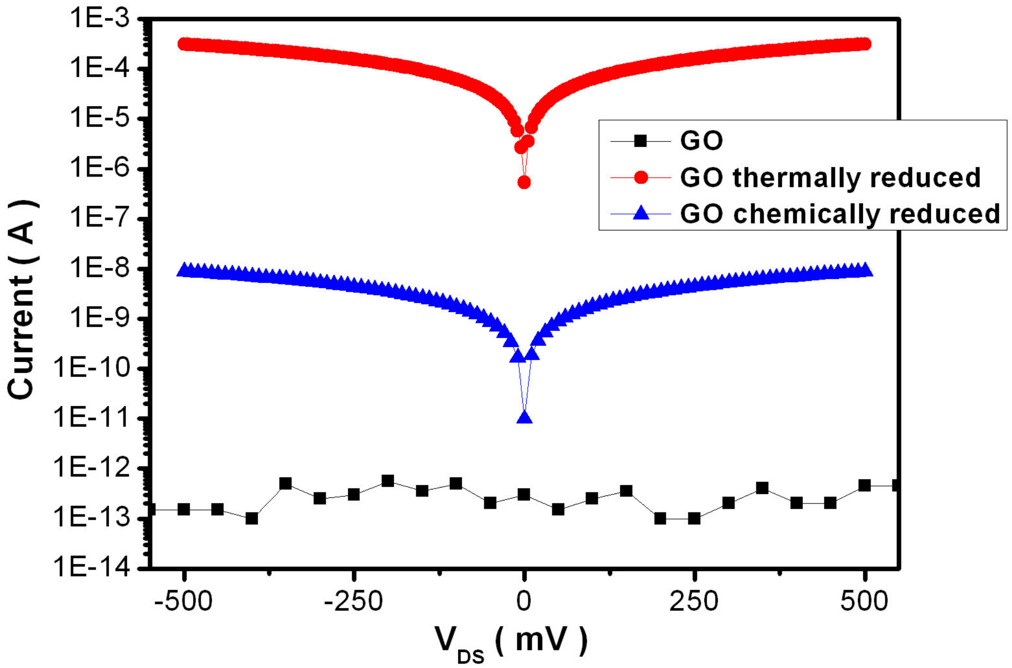


GO deposition



Reduction of GO

Reduction of graphene oxide has been performed both by a chemical protocol ($NaBH_4$) and a thermal one (700℃, UHV, slow ramp).



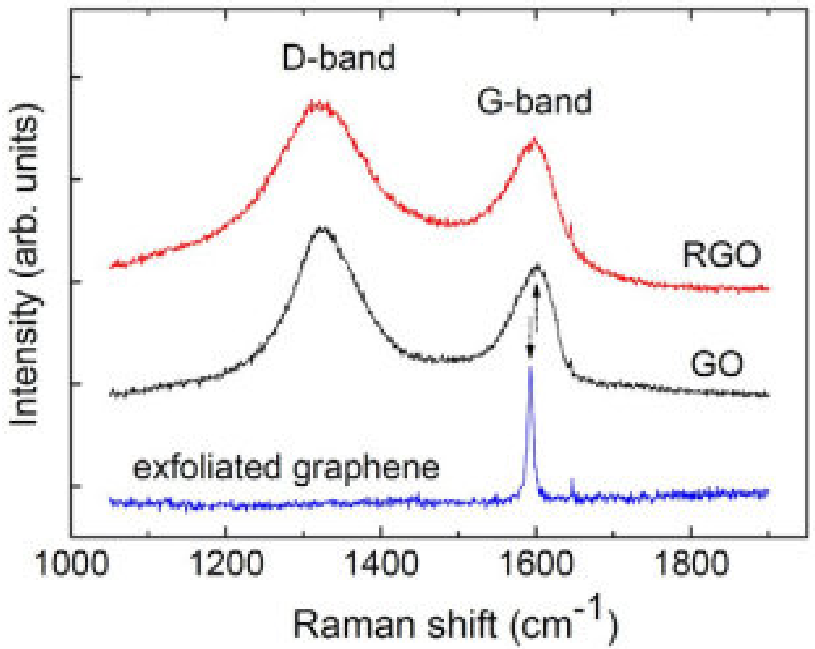
ρ chemical RGO ~ 10^4 Ω.cm
(not homogeneous and not clean)

ρ thermal RGO ~ 10^{-2} Ω.cm

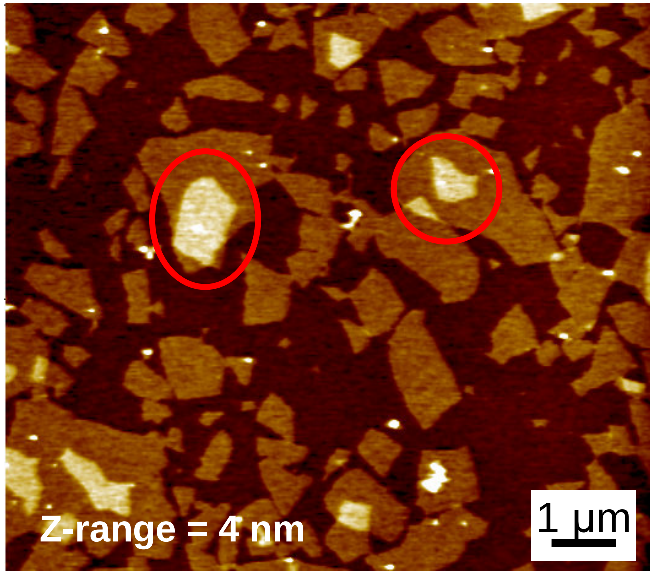
ρ exfoliated graphene ~ 10^{-5} Ω.cm

Even after thermal reduction →

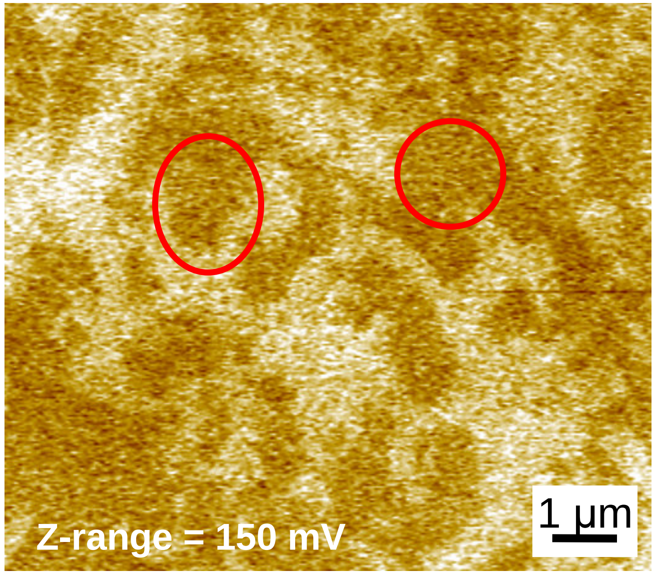
highly defective RGO



GO and RGO characterization



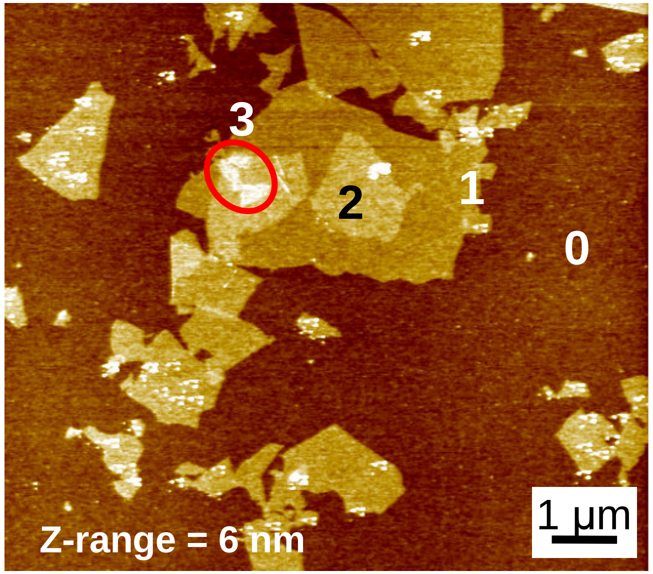
GO



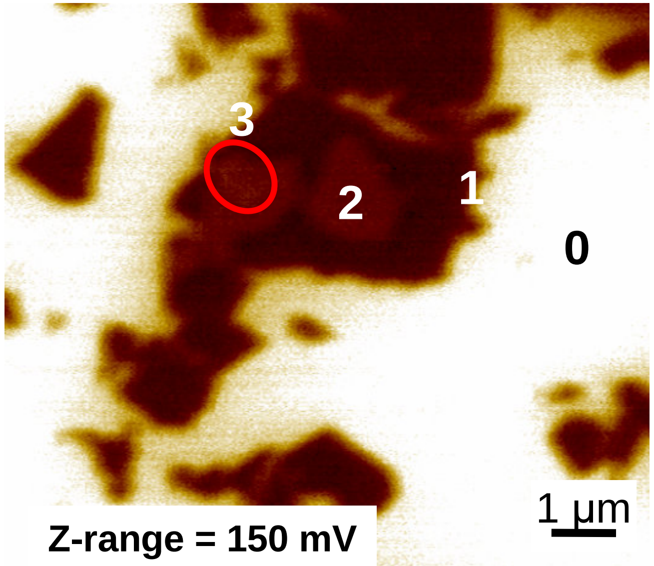
AFM

conc = 0.5 g/l

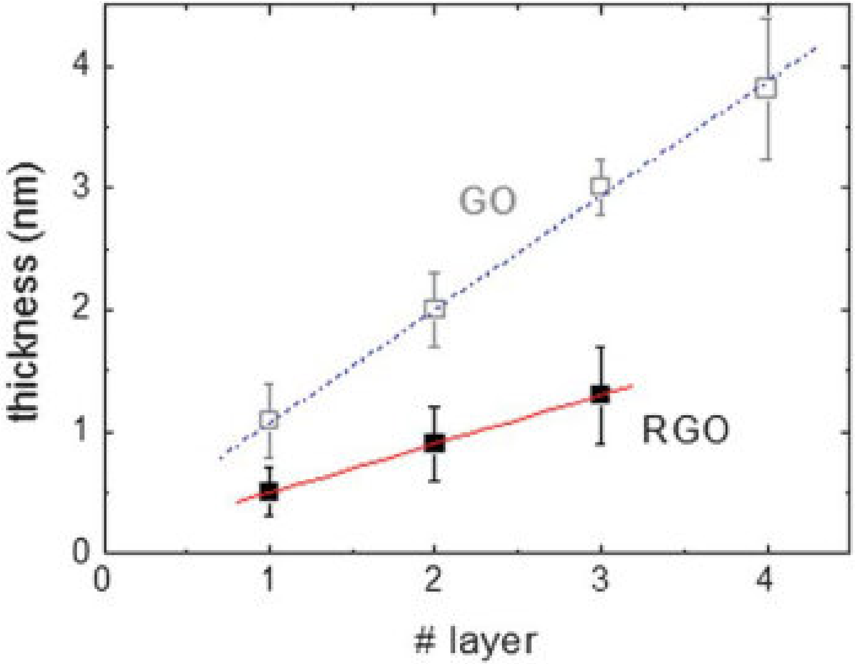
KPFM



RGO



GO and RGO characterization



AFM estimated sheet thickness

GO

1 layer = 1.1 ± 0.1 nm

Slope = 1.0 ± 0.1 nm

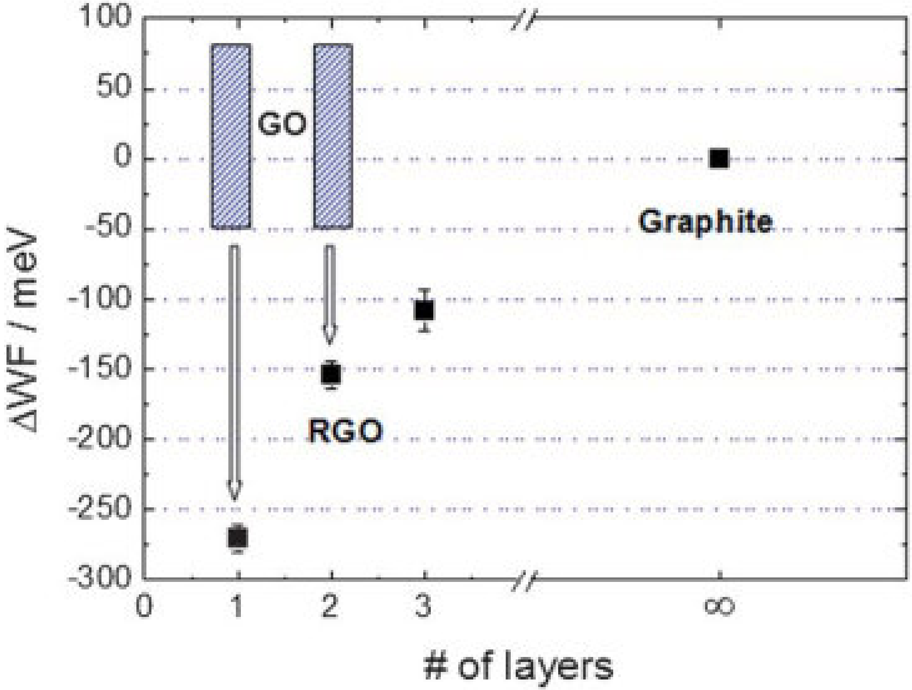
RGO (theory predicts t = 0.35 nm)

1 layer = 0.5 ± 0.2 nm (avg. on 2000 μm^2)

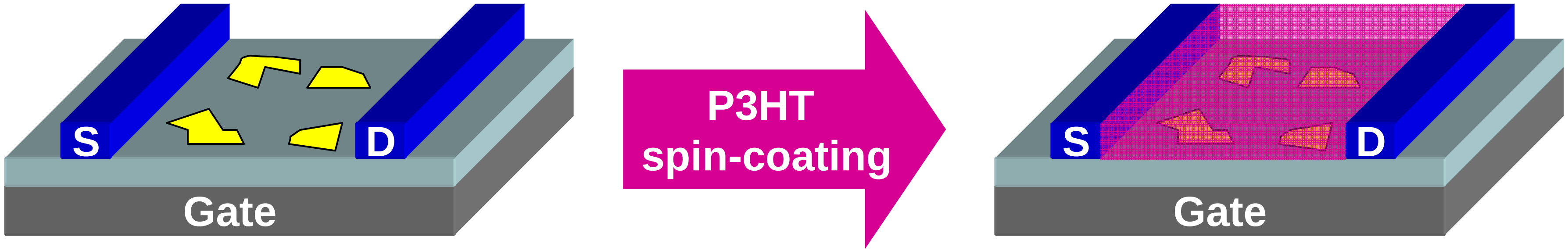
Slope = 0.4 ± 0.2 nm

KPFM

WF difference between single- and bi-layer is about 120 ± 10 meV

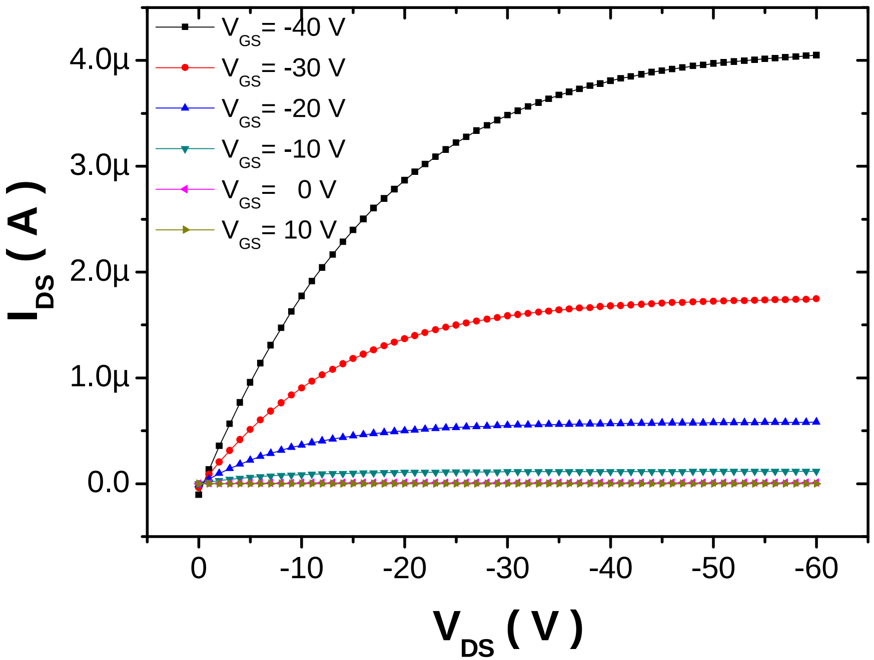


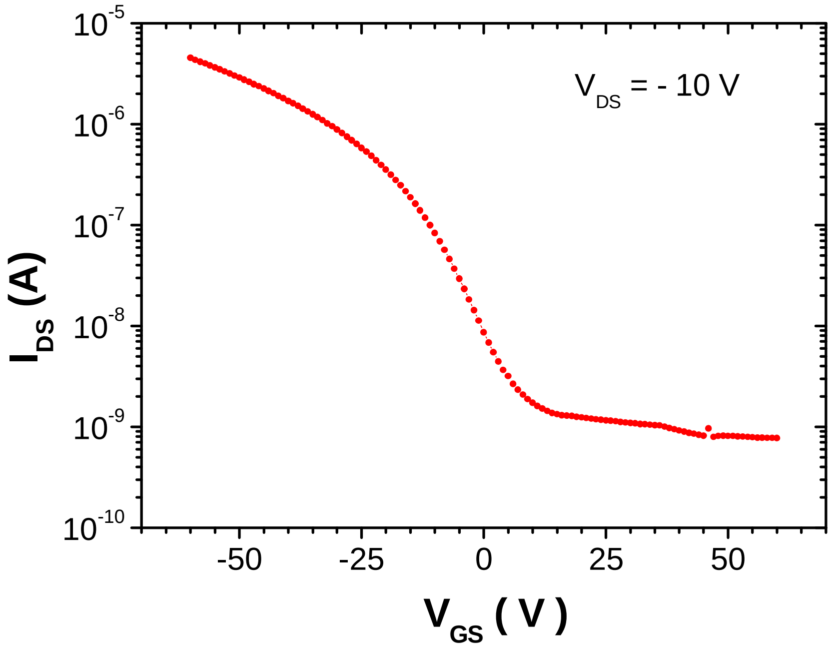
OFET fabrication and characterization



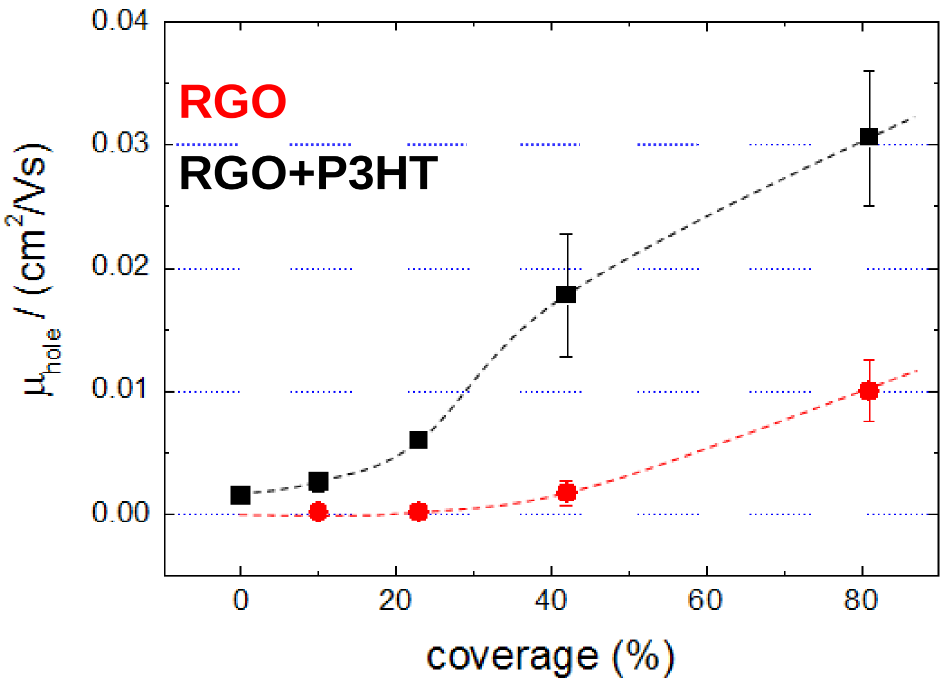
<Sheet size> ~ 300 nm L = 60 μm W/L = 200

23% RGO coverage (conc = 0.5 mg/ml) + P3HT spin coating



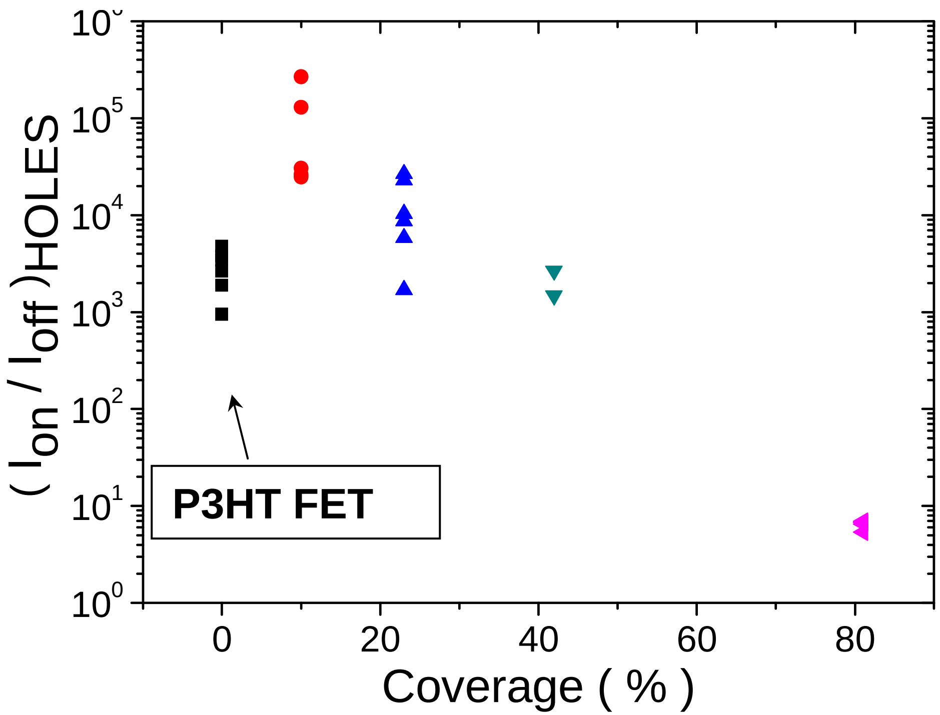


OFET fabrication and characterization

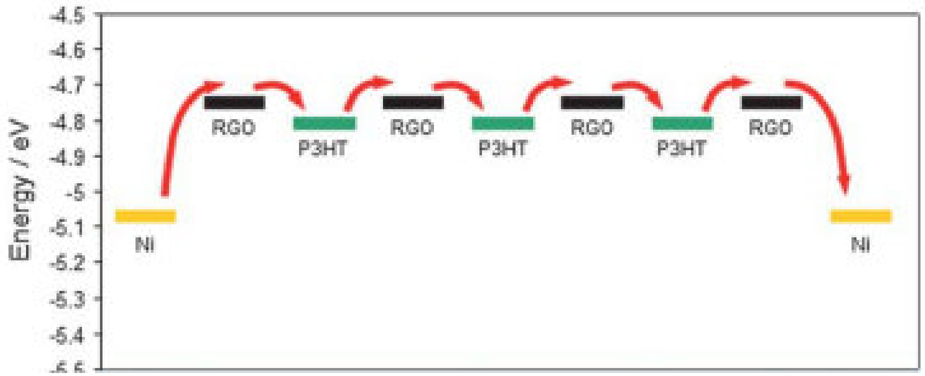


42% coverage RGO sheets – under the percolation threshold

- **mobility increases**
- **I_{on}/I_{off} (RGO+P3HT) ~ I_{on}/I_{off} (P3HT)**



KPFM

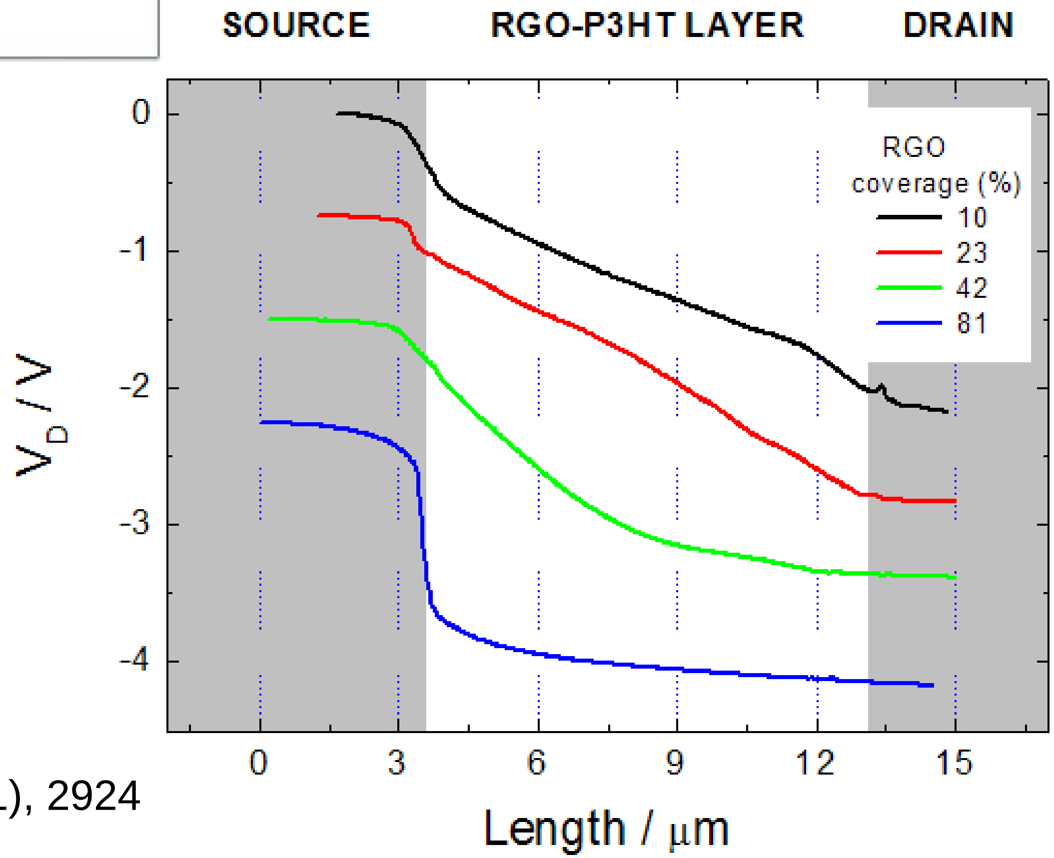


KPFM to determine work functions:

Ni → 5.07 ± 0.02 eV

RGO monolayers → 4.75 ± 0.02 eV

P3HT → 4.80 ± 0.03 eV



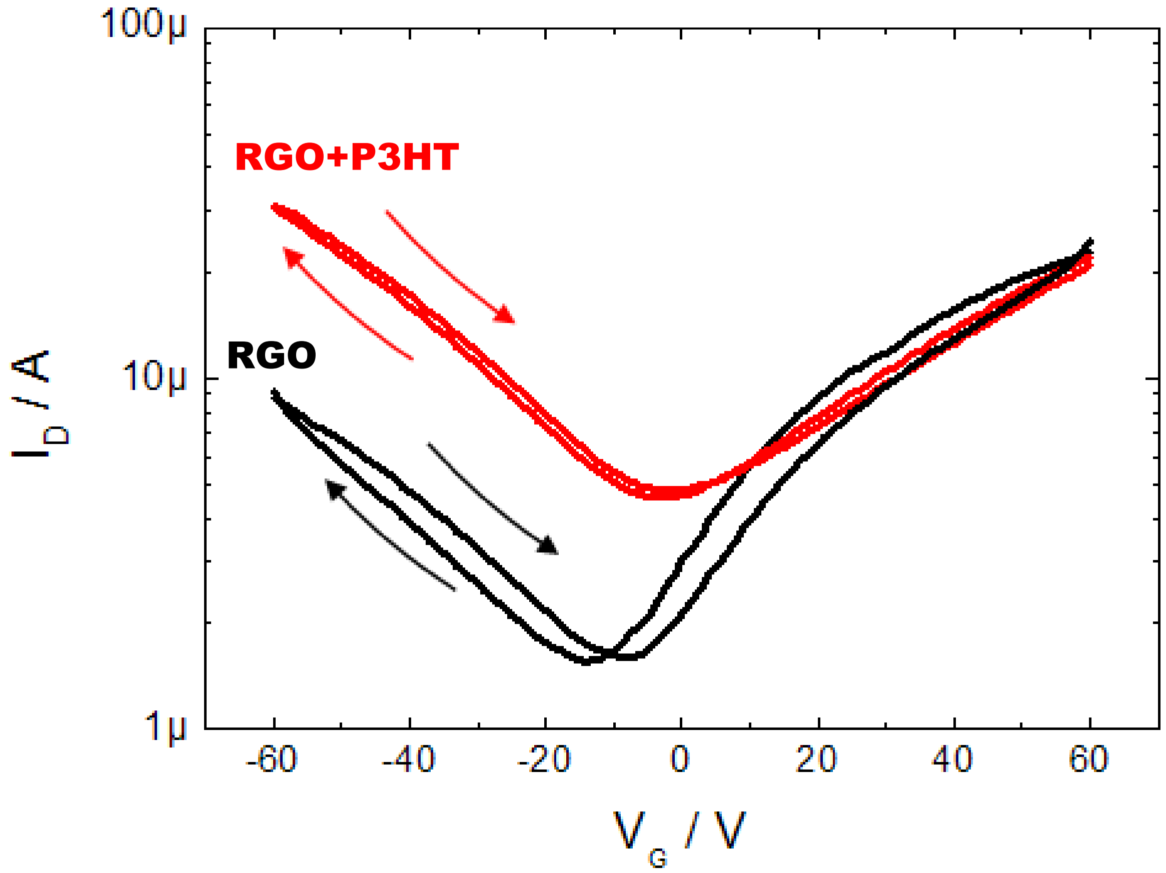
<Sheet size> ~ 300 nm
L = 10 µm

V_{DS} = 2 V

V_G = 0 V

More details in
A. Liscio et al. J. Mater. Chem 21 (2011), 2924

Ambipolar FET



Transfer curve for continuous RGO layer, A=82%, 2 mg/ml

linear regime
V_{DS} = - 10 V

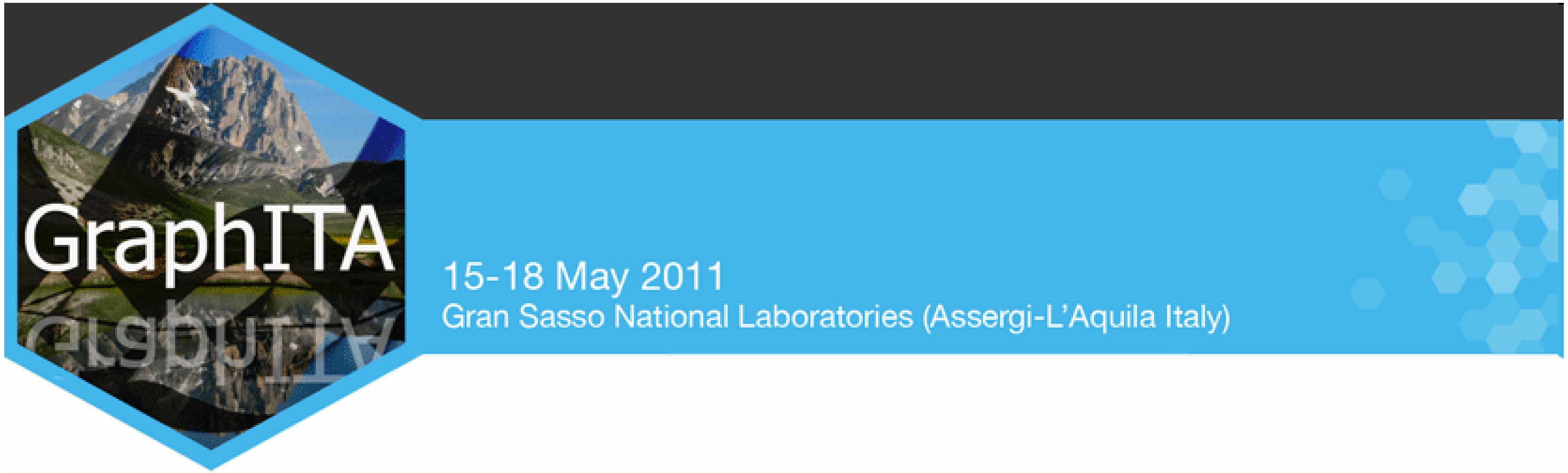
Holes mobility increases when P3HT (hole transport) is spin-coated on percolated RGO film - P3HT can help the hole transport around defects and bottle neck connection between RGO sheets

Conclusions

Graphene based materials can help improving OS device performances.

Investigating P3HT-RGO blends properties, it has been possible to:

- Define a well-controlled and versatile technique for the preparation and deposition of RGO sheets with selected features;
- Investigate charge transport at OS / graphene interfaces;
- Improve mobility and I_{ON}/I_{OFF} in P3HT- based OFET in a tuneable way;
- Define a protocol for testing different graphene-OS blends


GraphITA
15-18 May 2011
Gran Sasso National Laboratories (Assergi-L'Aquila Italy)

Thank you !!!