chem2Dmat

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EUROPEAN CONFERENCE ON CHEMISTRY OF TWO-DIMENSIONAL MATERIALS

Parallel Workshop 1

1st September 2021

Charge transport mechanisms in GRM thin films: interplay between different length scales

Alex Boschi

alex.boschi@isof.cnr.it

Istituto per la Sintesi Organica e la Fotoreattività (ISOF)
CNR – Bologna, Italy

ISOF CNR

UNIVERSITAS STUDIORUM MUTINENSIS ET REGIENSIS 1175

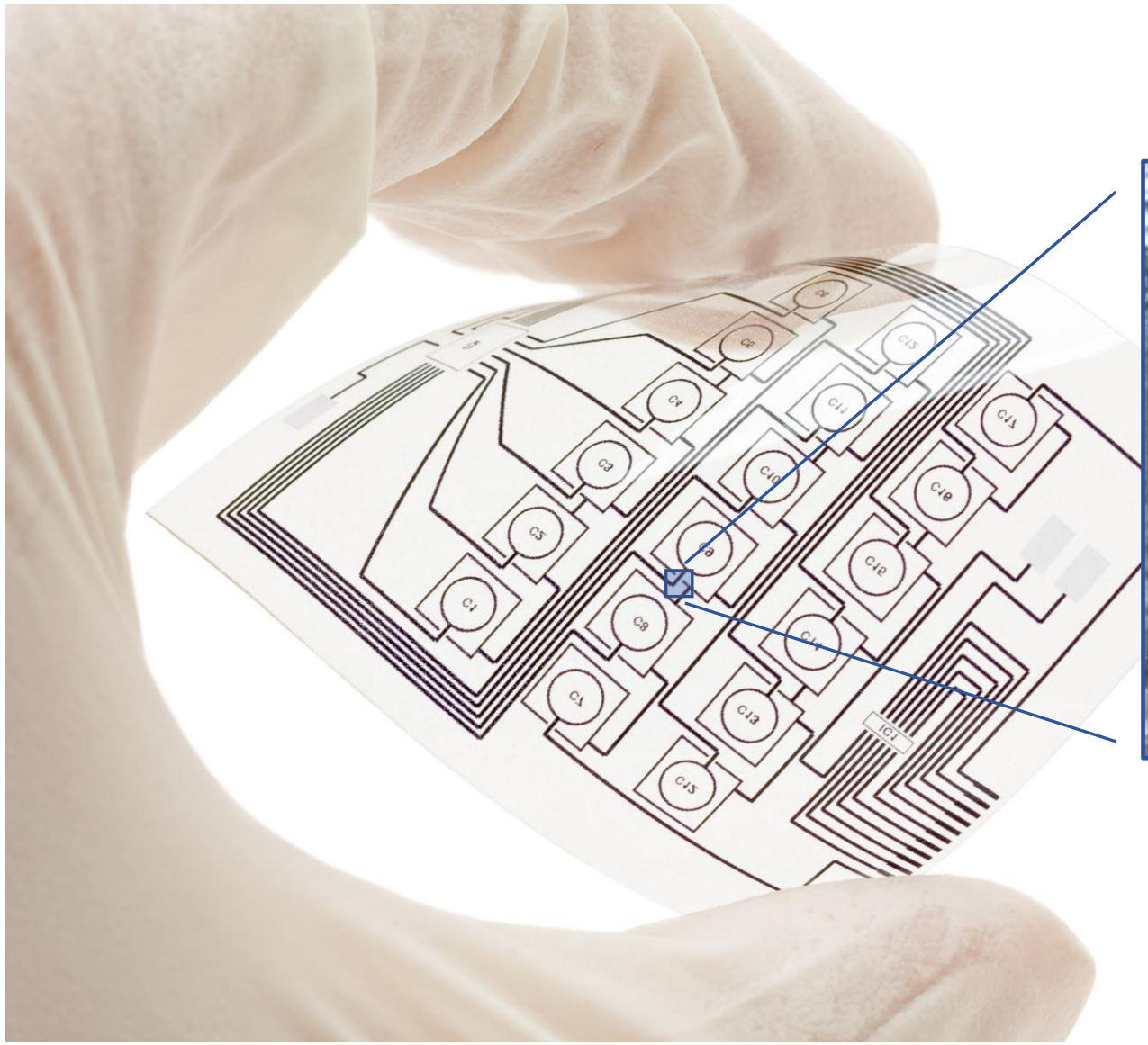
UNIMORE
UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA

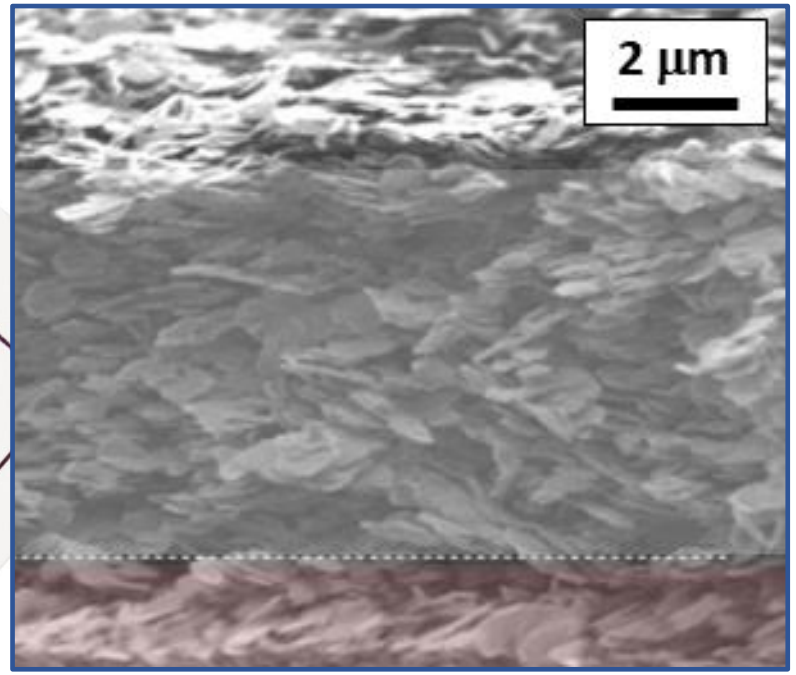
GRAPHENE FLAGSHIP

Outline

- Purpose of the work
- Structural characterization of GRM samples
- Charge transport in GRM thin films

2-Dimensional materials printed electronic devices

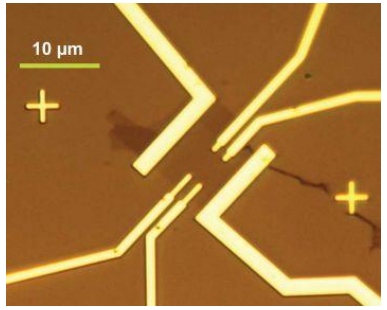




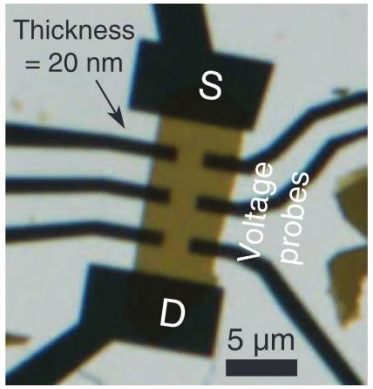
Kelly *et al.*, *Science* 356, 6333 (2017)

In between single-sheet devices and bulk materials

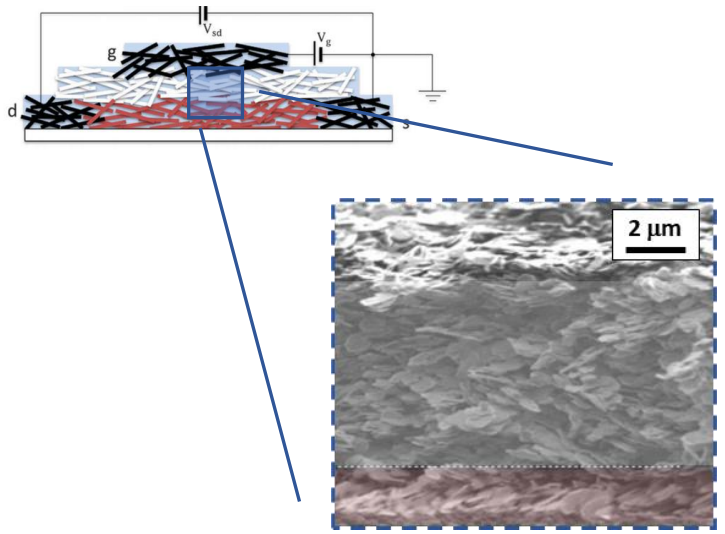
Charge transport in single sheet devices



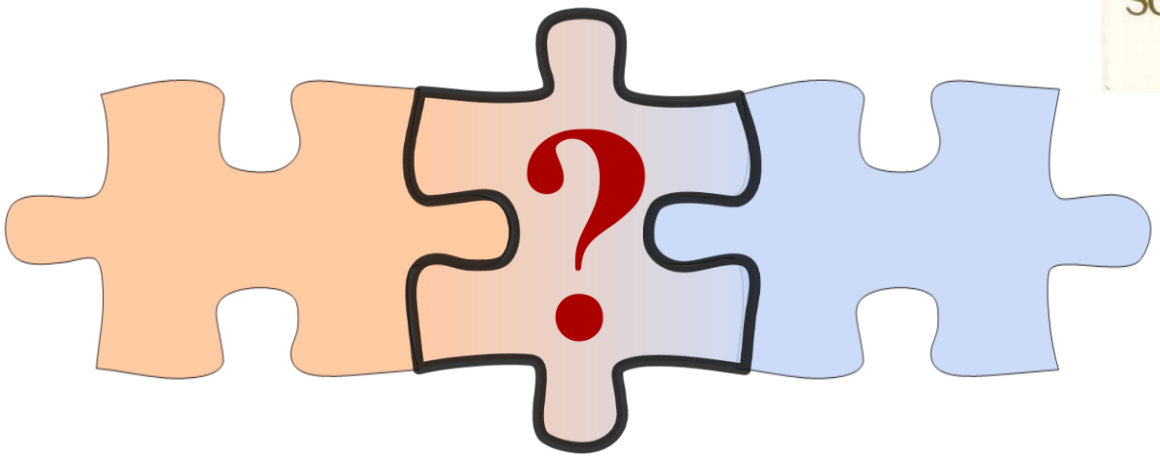
Joung *et al.*, *Phys. Rev. B* 86, 235423 (2012)



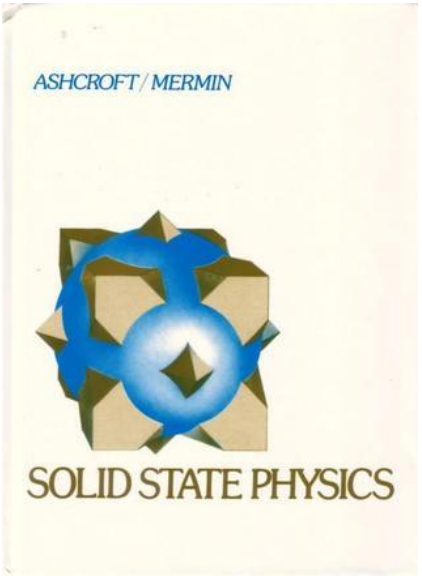
Ye *et al.*, *Science 338*, 1193 (2012)



Kelly *et al.*, *Science* 356, 6333 (2017)

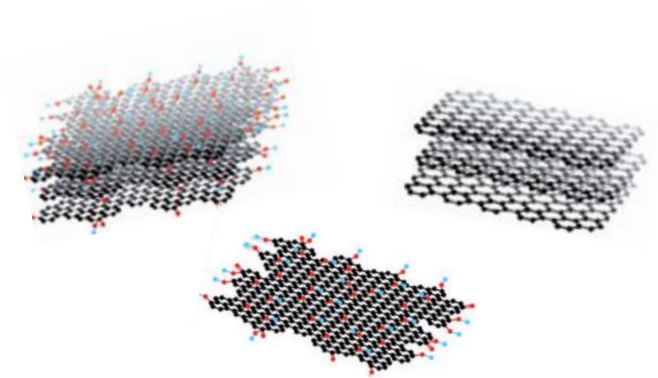


Charge transport in bulk systems

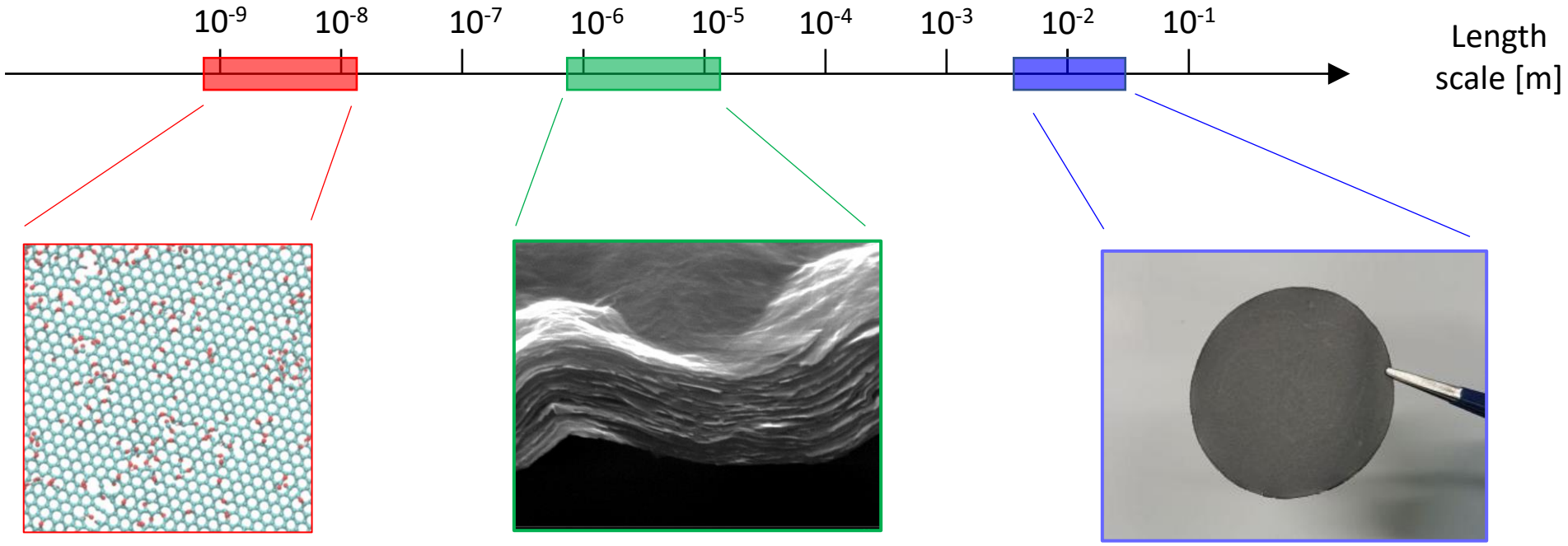


GRMs as test model to study multiscale systems

Graphene-related Materials (GRM)



- ✓ 2D materials
- ✓ wide portfolio of processing methods
- ✓ (some) commercially available



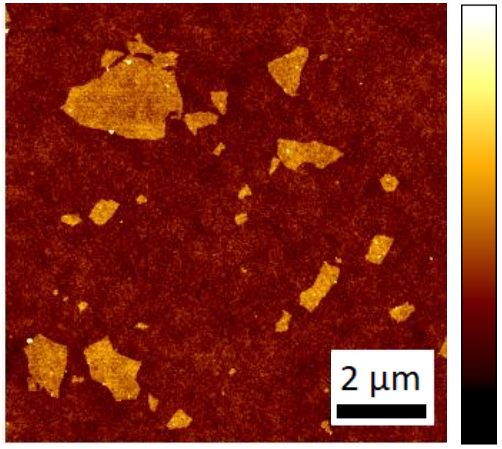
Two different GRM nanosheets

AFM

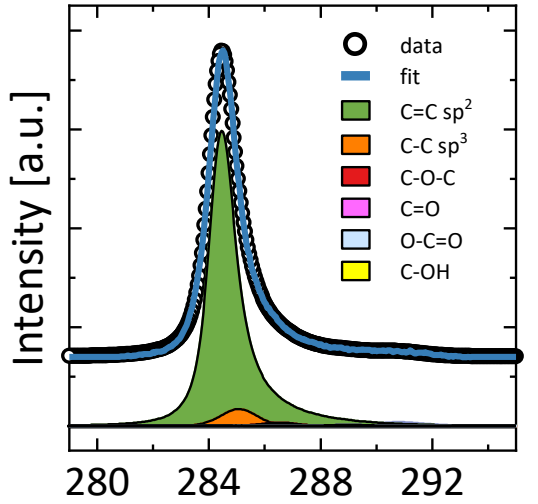
XPS

Reduced Graphene Oxide (**RGO**)

- ✓ purely 2D material
- ✓ negligeable oxygen contenent

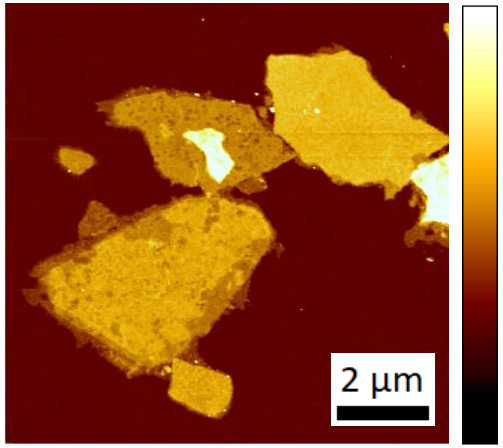


z-range: 2.5 nm

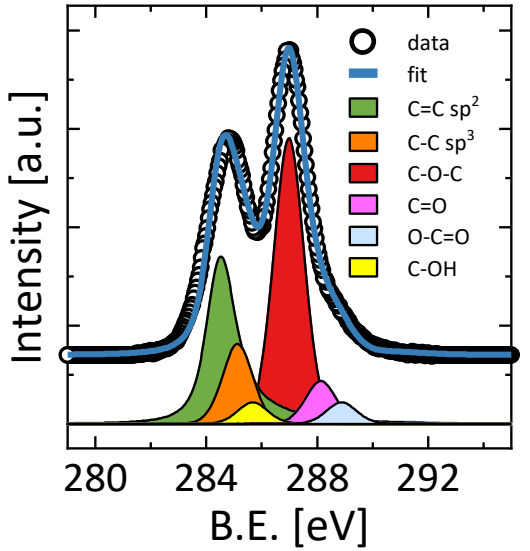


Electrochemical Exfoliated GO (**EGO**)

- ✓ multilayer nanosheets
- ✓ oxygen functionalities

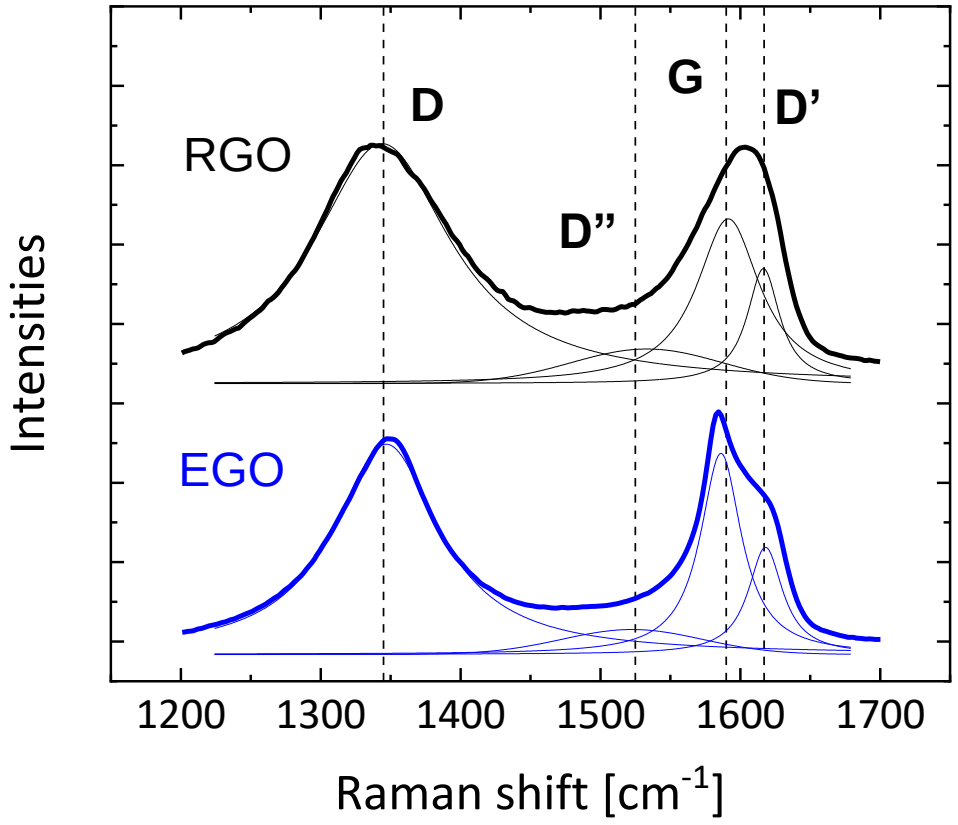


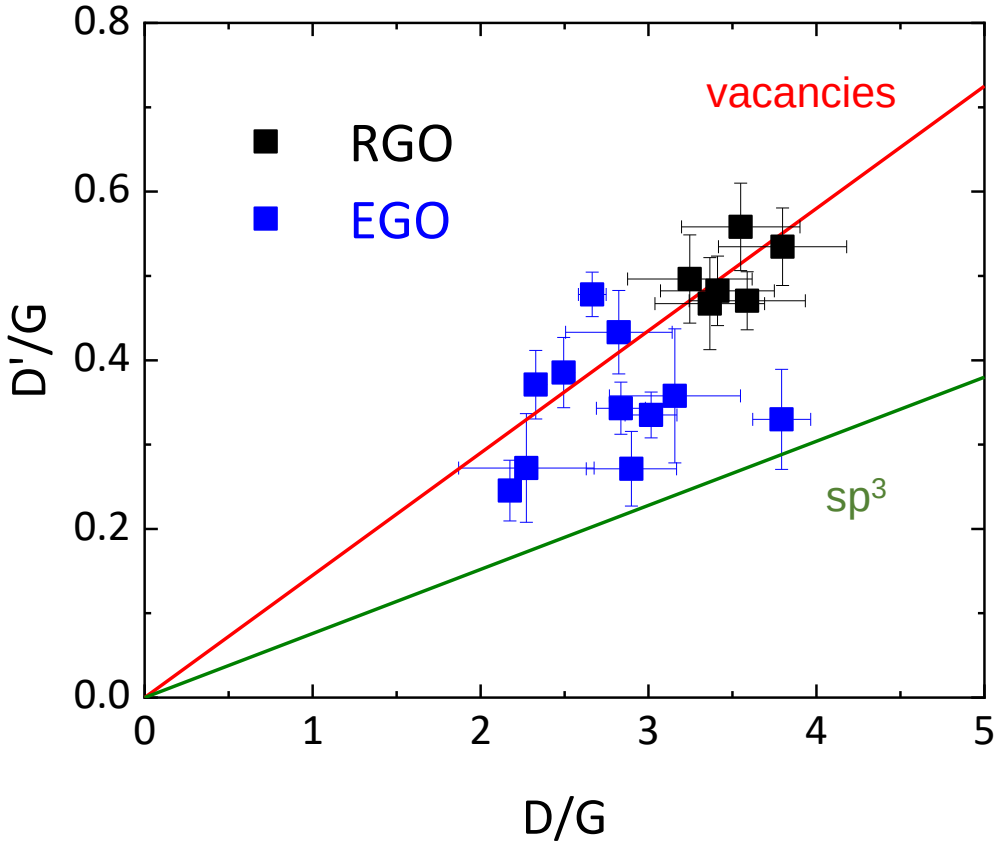
z-range: 11 nm



Raman spectroscopy for understanding the nature of nanosheet defects

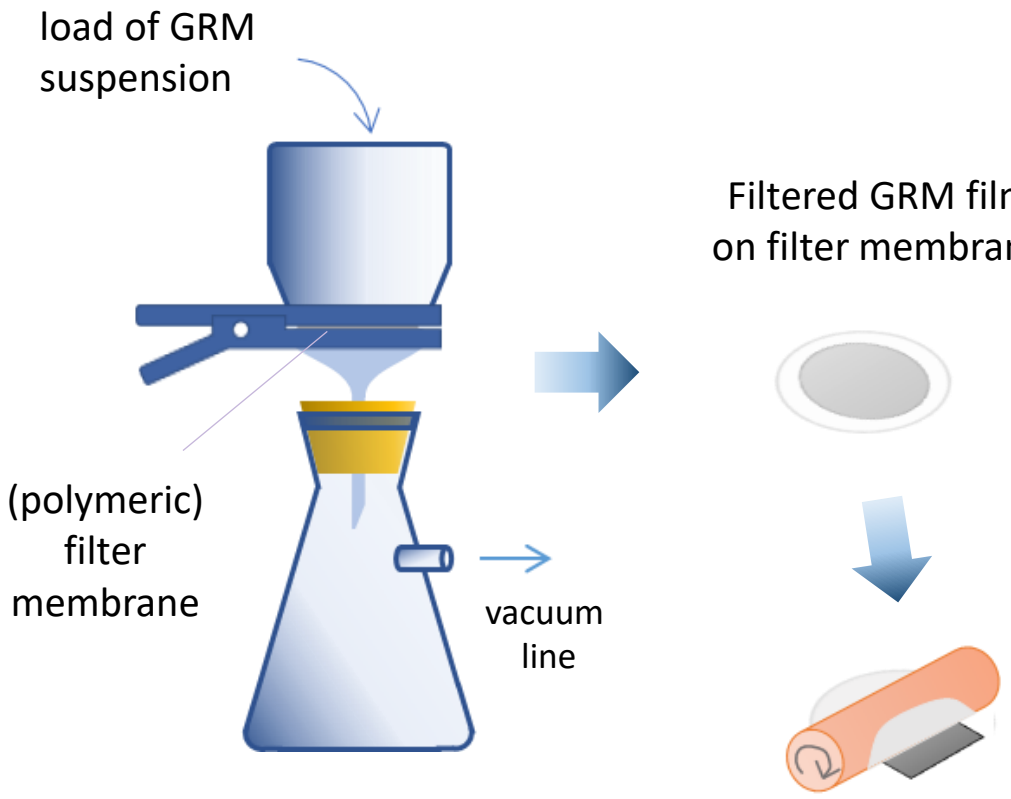
representative Raman spectra



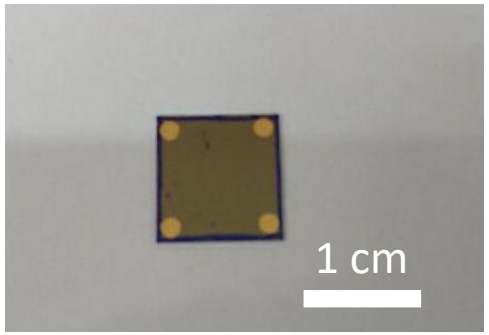


Macroscopic GRM thin films

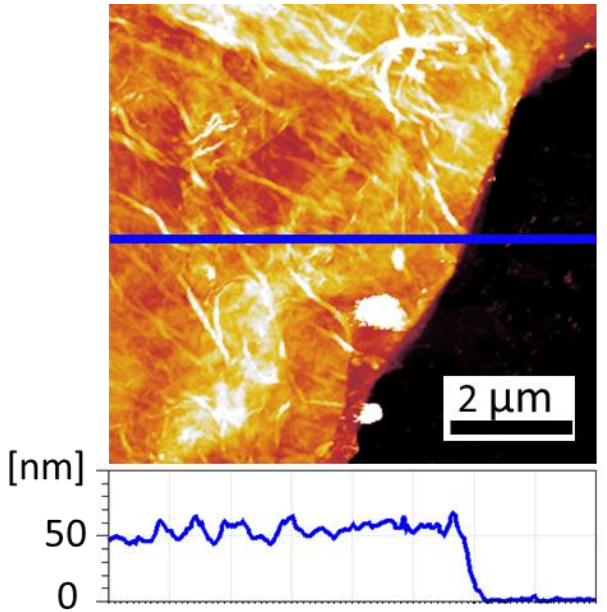
vacuum-assisted filtration deposition



photograph of a film



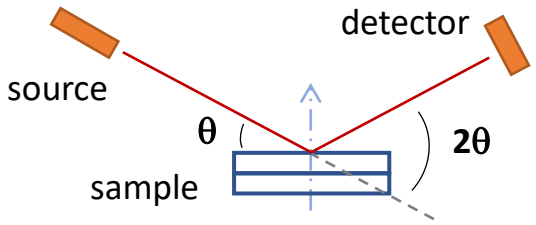
AFM image

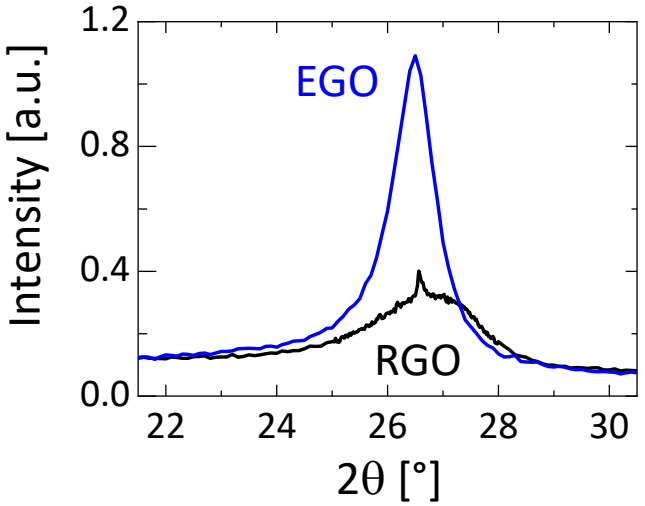


Film network structure: RGO *vs.* EGO

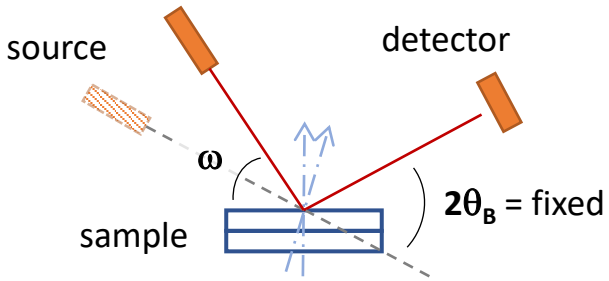
XRD measurements on GRM films

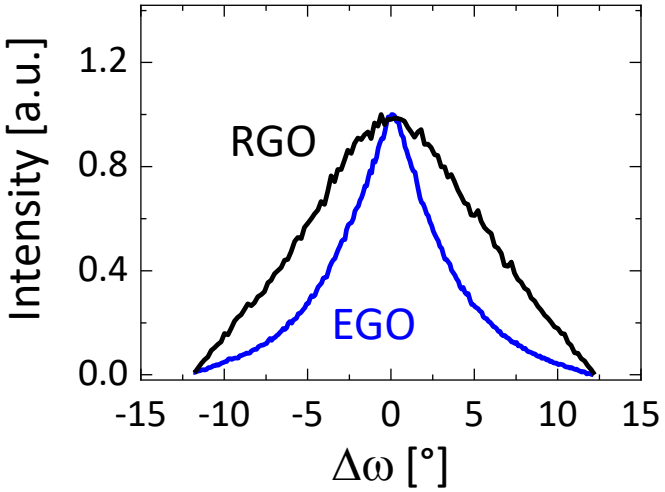
Specular Scan θ-2θ

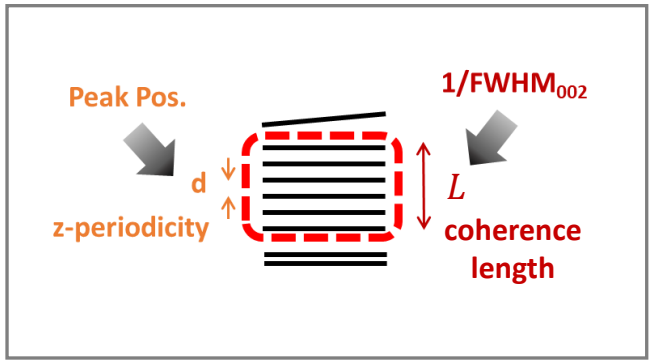




Rocking Curve







Mosaicity (M)
=
mis-allignment between crystallites in the film

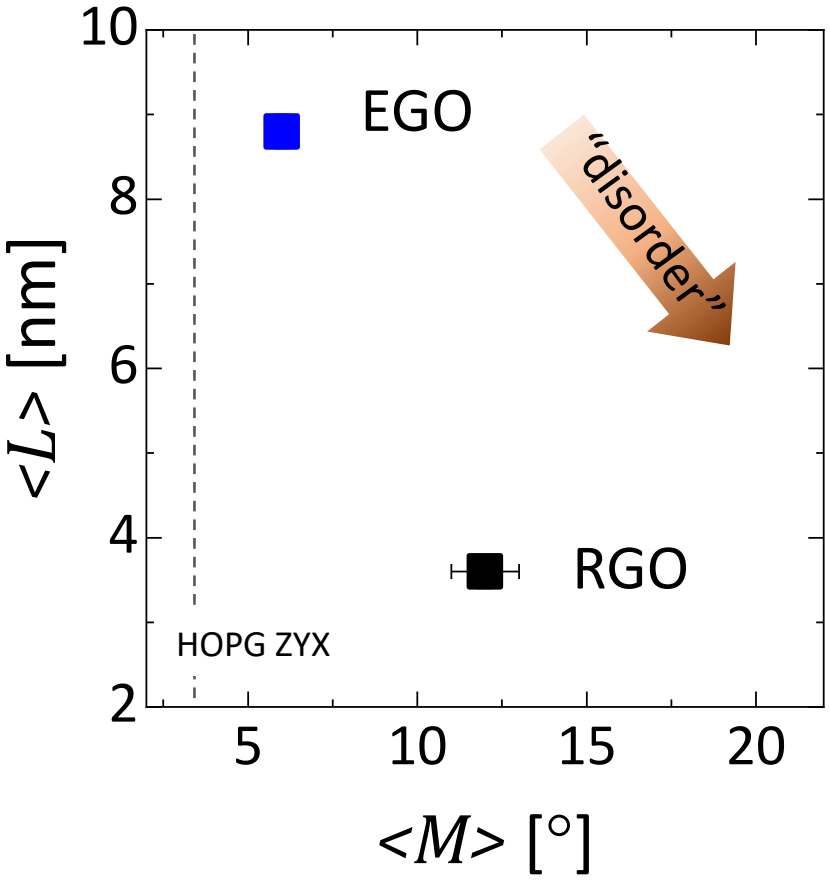
out-of-plane structural information about the films

Film network structure: RGO *vs.* EGO

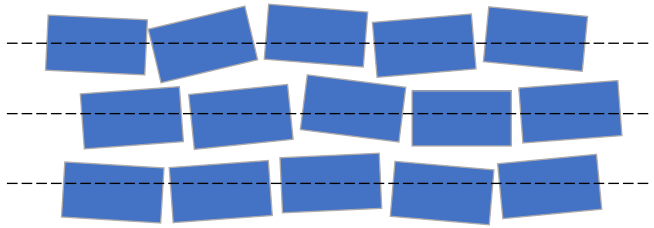
XRD measurements on GRM films

Specular Scan θ-2θ

Rocking Curve



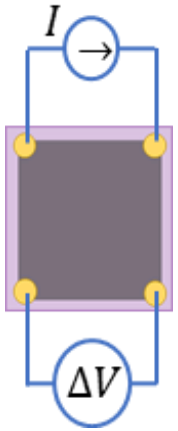
RGO



EGO

few stacked single sheets

a partially oxidised single flake



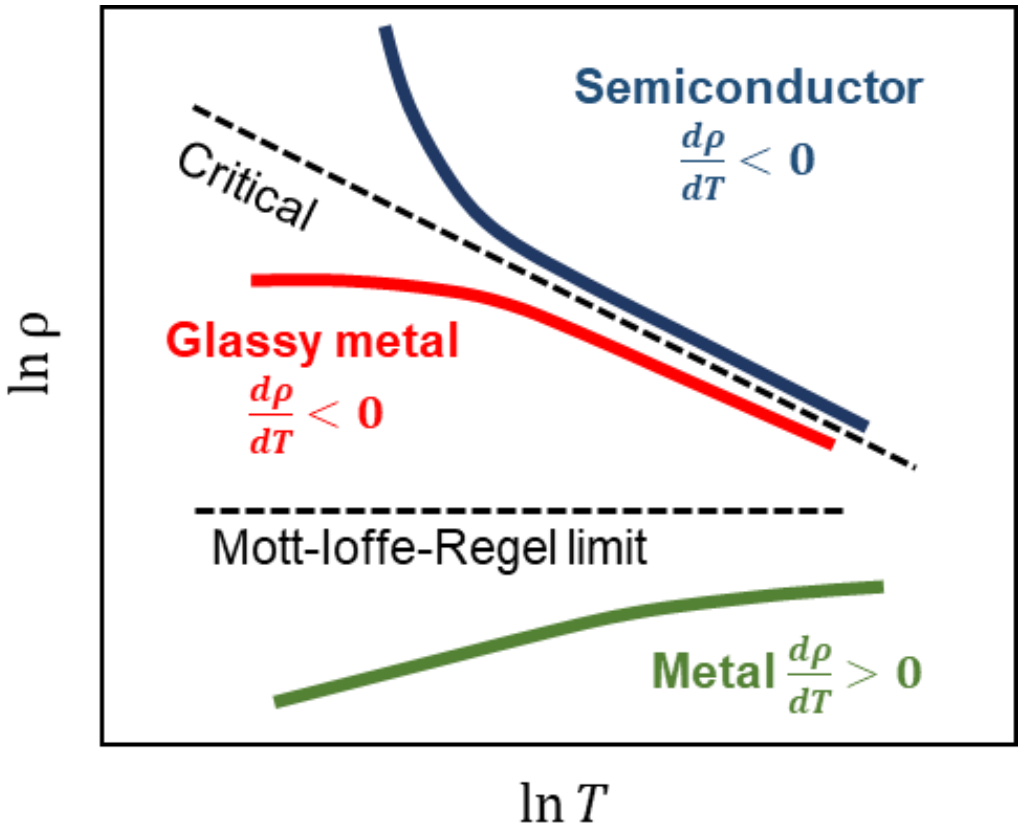
room temperature

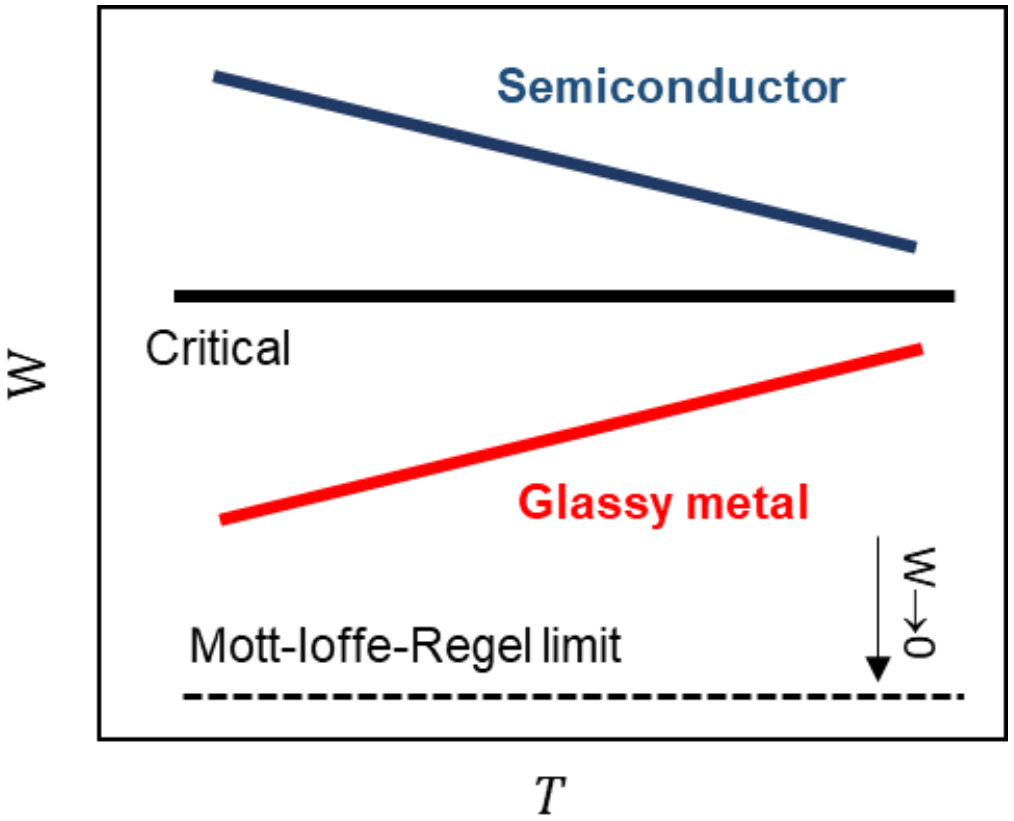
resistivity of similar order: 10^{-5} Ω·m !

Charge transport in a nutshell

resistivity ρ as a function of temperature

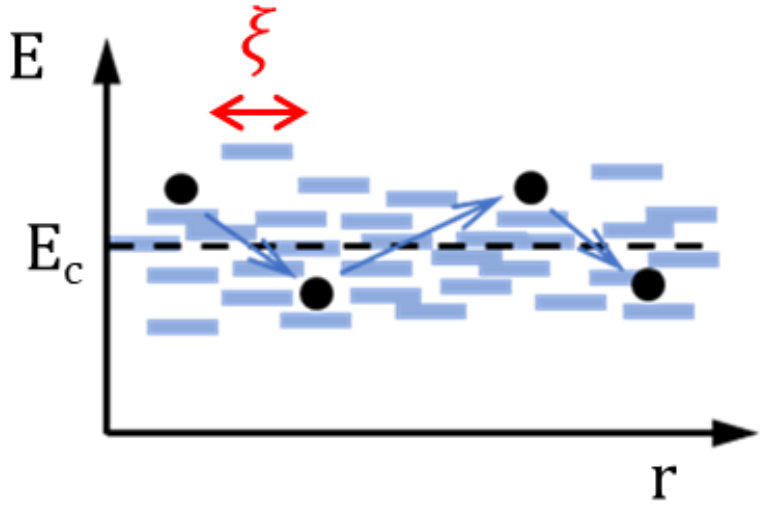
activation energy $W = -\frac{\partial \ln \rho(T)}{\partial \ln T}$





Zabrodskii, Zh. Eksp. Teor. Fiz 86, 727 (1984)

Variable Range Hopping (VRH)



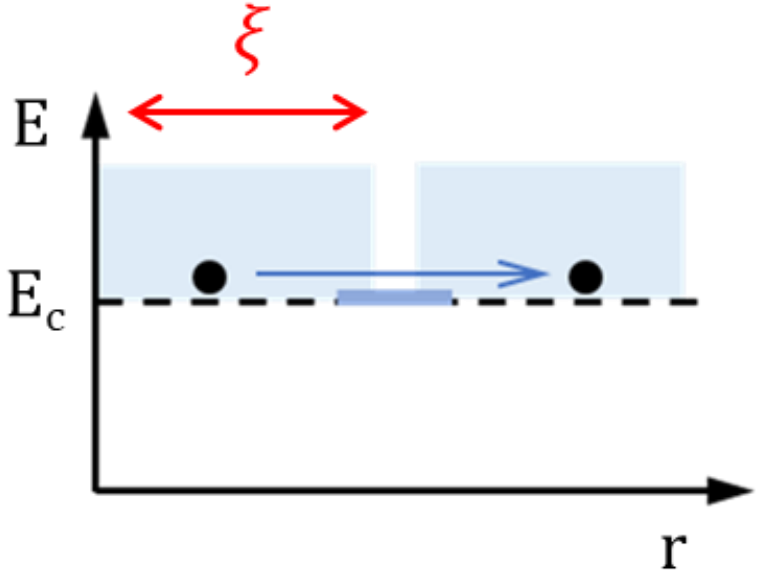
$$\rho(T) \sim e^{\left(\frac{T_0}{T}\right)^p}$$

p depends on Density of States $g(\mu_F)$ shape

p	
1/2	1D system, $g(\mu_F) \neq 0$
1/3	2D system, $g(\mu_F) \neq 0$
1/4	3D system, $g(\mu_F) \neq 0$
1/2	$g(\mu_F) = 0$

Power law (PL)

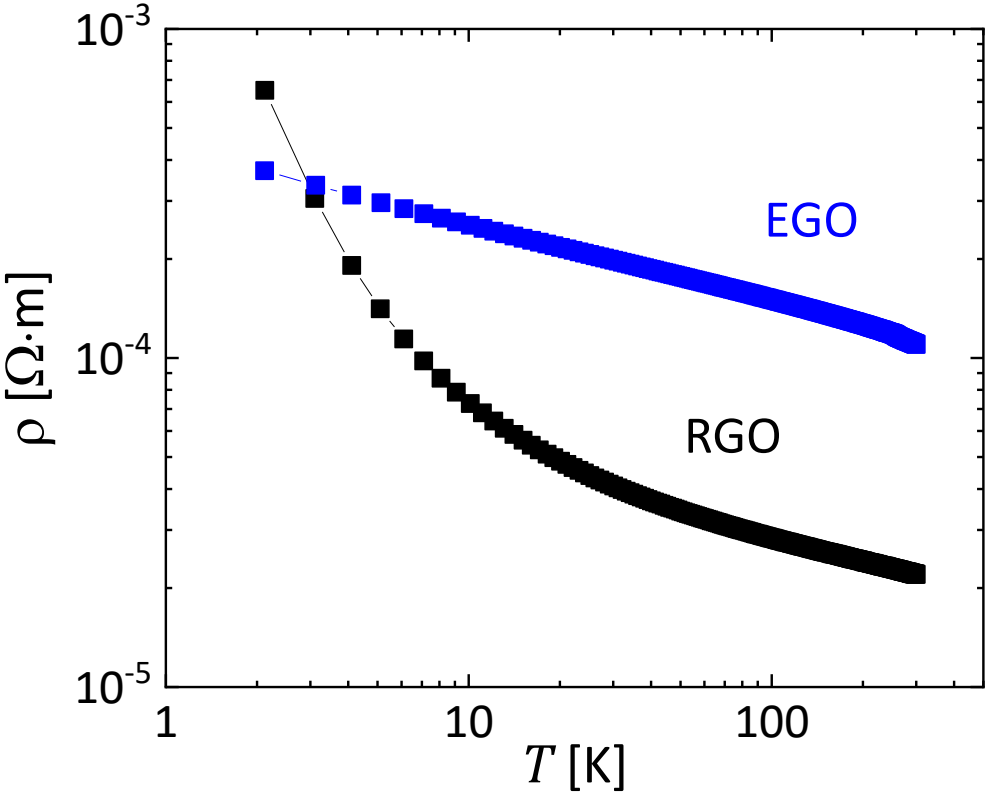
- ✓ critital regime
- ✓ nuclear tunnelling
- ✓ etc



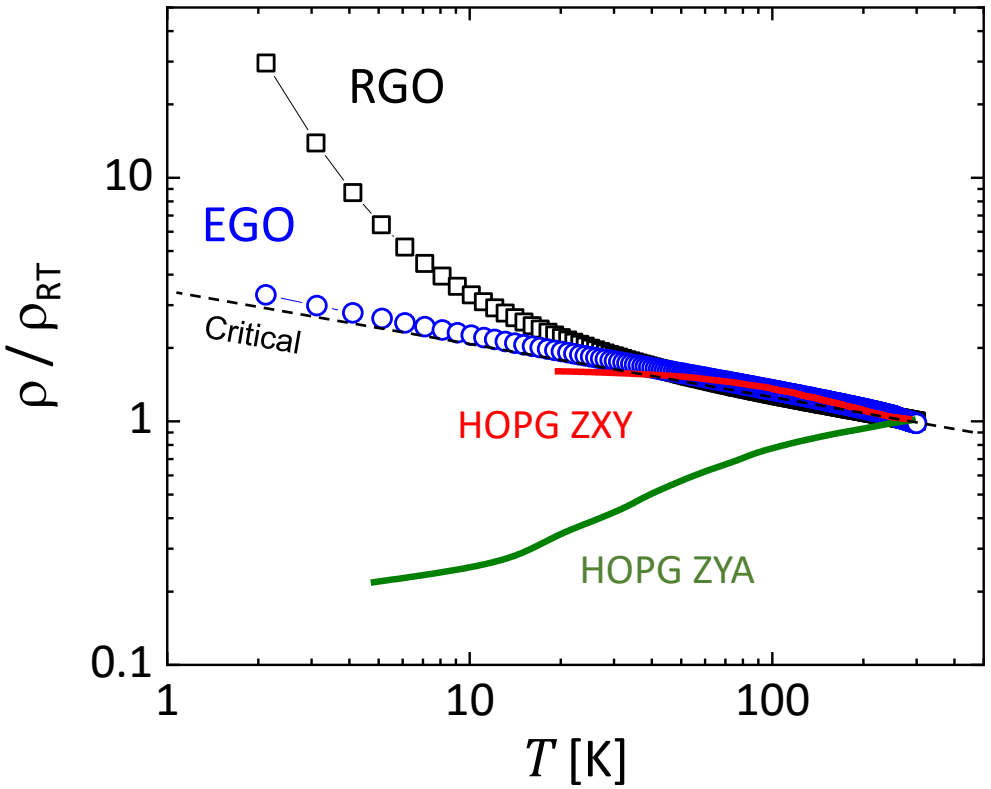
$$\rho(T) \sim T^{-m}$$

ξ: localisation length

ρ(T) for GRM films

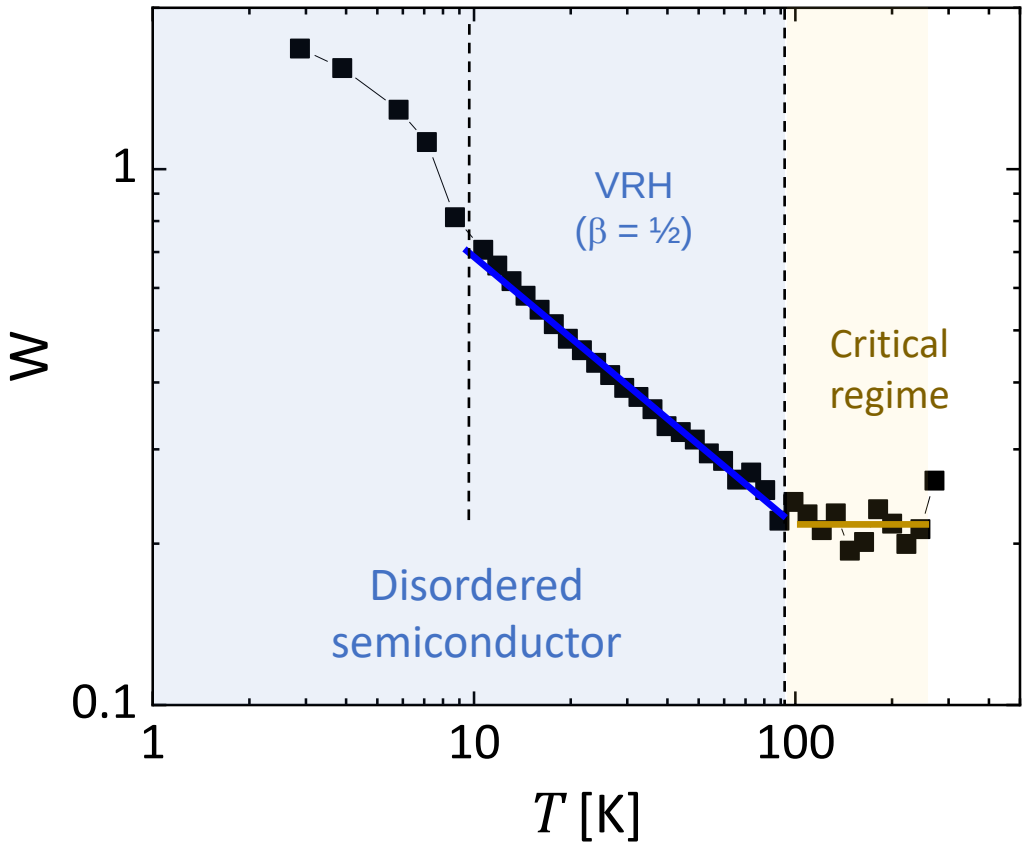


normalised resistivity

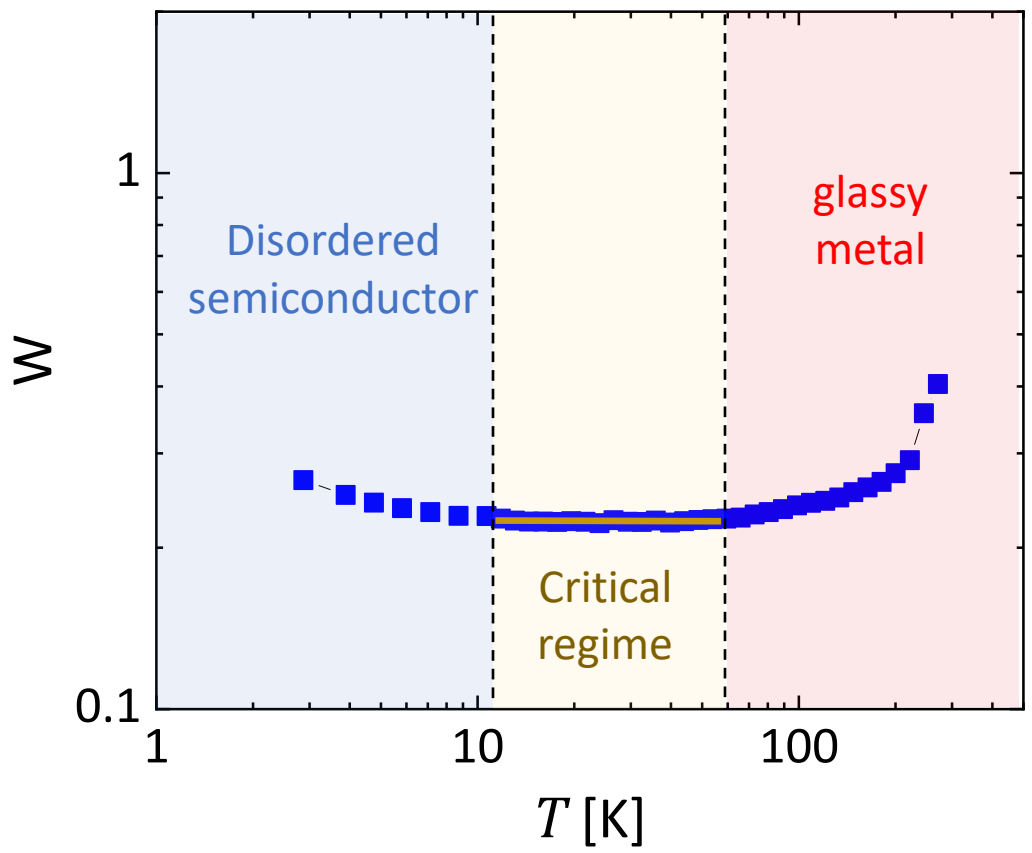


Charge transport analysis for GRM films

RGO



EGO

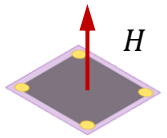


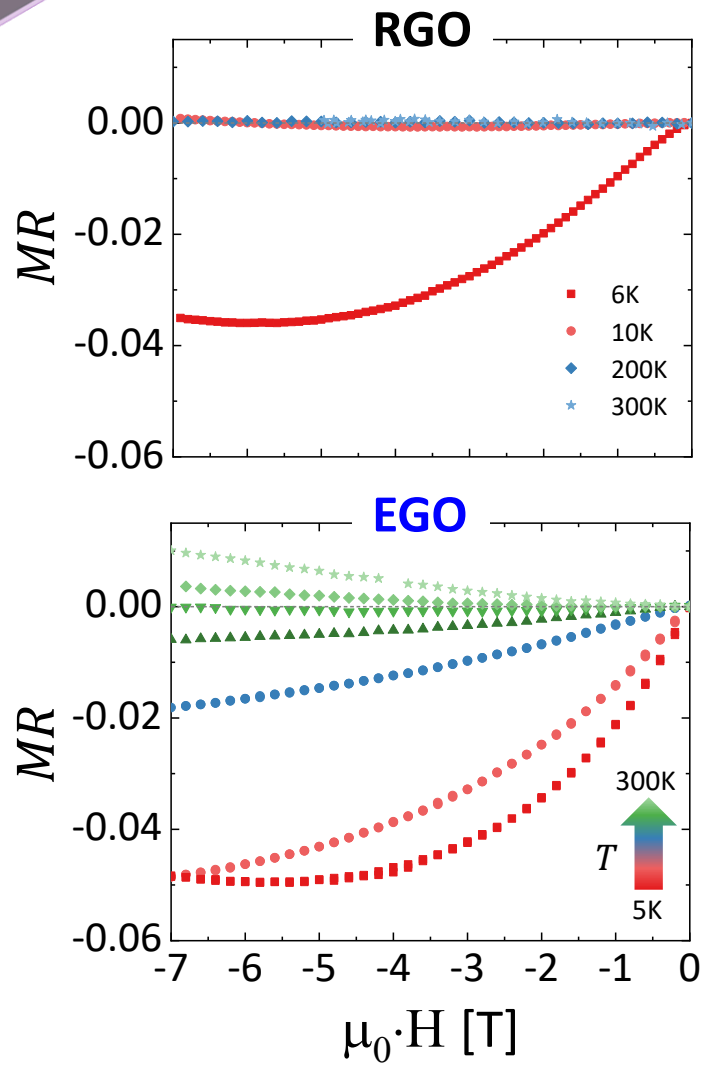
Observed for 35 different RGO systems!!

A. Kovtun et al., *ACS Nano* 15, 2654 (2021)

activation energy $W = -\frac{\partial \ln \rho(T)}{\partial \ln T}$

Magnetoresistance as a tool for understanding charge transport mechanisms





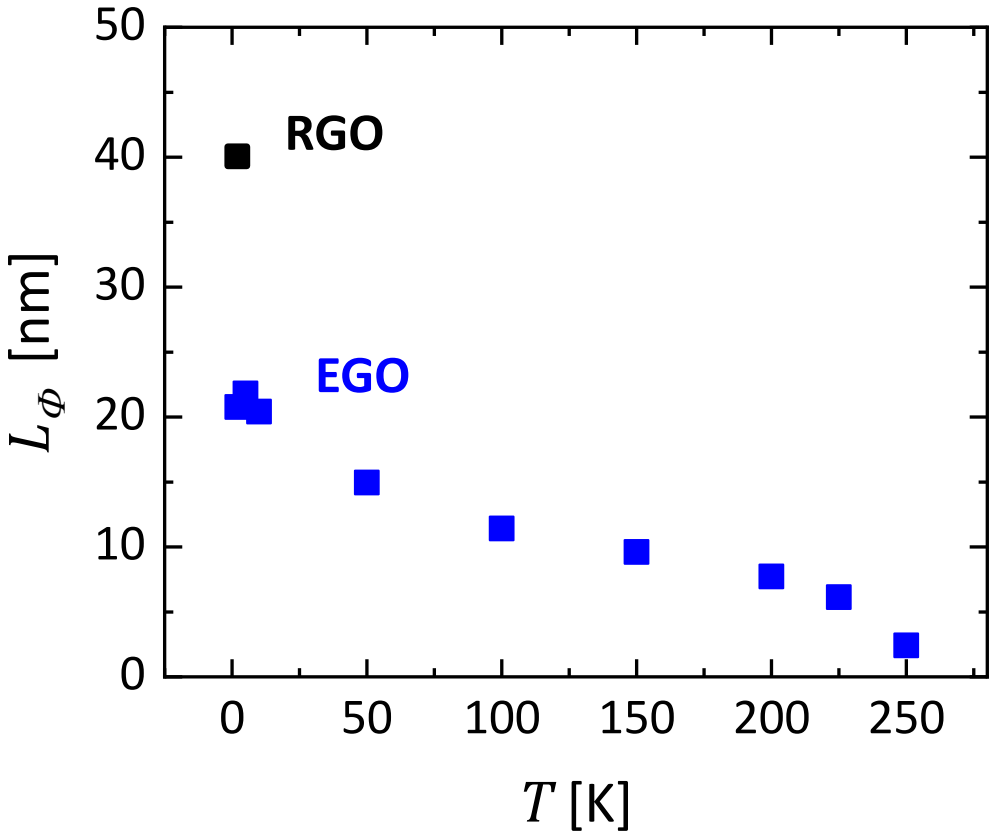
$$\mathrm{MR(T)}=\frac{\rho(T,H)-\rho(T,0)}{\rho(T,0)}$$

Weak Localization effects

$$\frac{\mathrm{MR}-\beta\cdot\mu_0\cdot H^2}{\rho}=-C\cdot L_\phi^3\cdot H^2 \qquad \text{for } \mu_0 H \lesssim 2\mathrm{T}$$

localization length

P. A. Lee, *Rew. Mod. Phys. 57, 2 (1985)*



Electrical noise measurements

voltage-spectral density

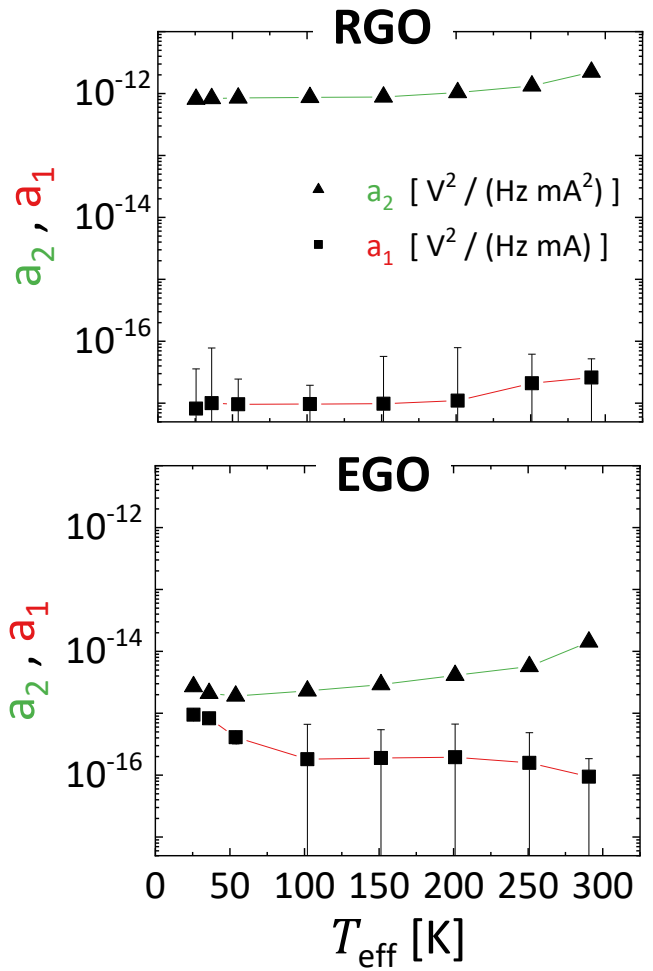
$$S_V(f) \approx \frac{K(I,T)}{f} + S_{white}$$

flicker noise

$$K(I,T) = a_2 I^2 + a_1 I + a_0$$

ELECTRICAL NOISE

fluctuation of an electrical quantity



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Andrea Candini (Res)

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Samuel Lara Avila (Prof)

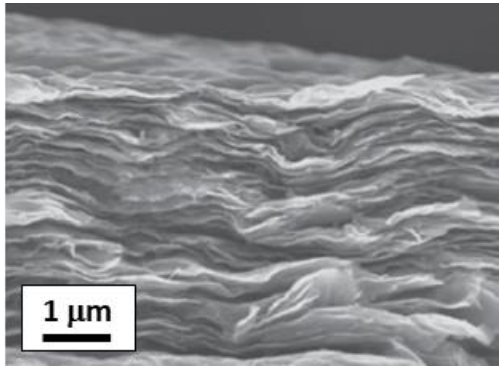
Kyung Ho Kim (Former post-doc)

University of Salerno (IT)

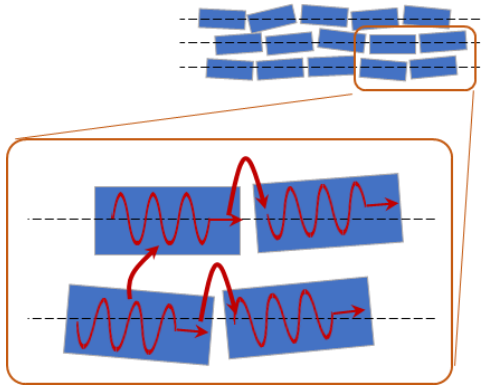
Carlo Barone (Prof)

Sergio Pagano (Prof)

Take home messages



- graphene-related materials (GRM) to study electrical properties of networks



- similar macroscopic electrical resistivities, different charge transport behavior depending on network nano- and micro- scale structure

Let’s discuss...

ALEX BOSCHI

alex.boschi@isof.cnr.it

CNR – ISOF @ Bologna (IT)