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Properties of Graphite Oxide, Carbon Nanotubes and their Composite Effect of Irradiation

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Collaboratations

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Sample preparation, characterization:

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TEM, modelling:

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Max Planck Institute, Stuttgart

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Dong Su Lee
Hye Jin Park

Hungarian Academy of Sciences:

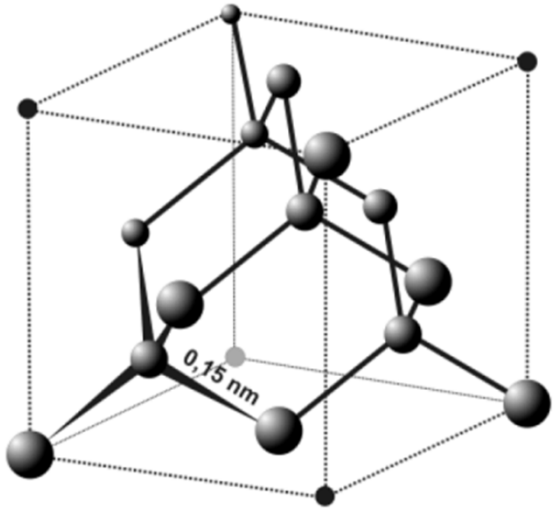
Ion irradiation:

Zsolt E. Horvath
Laszlo P. Biro

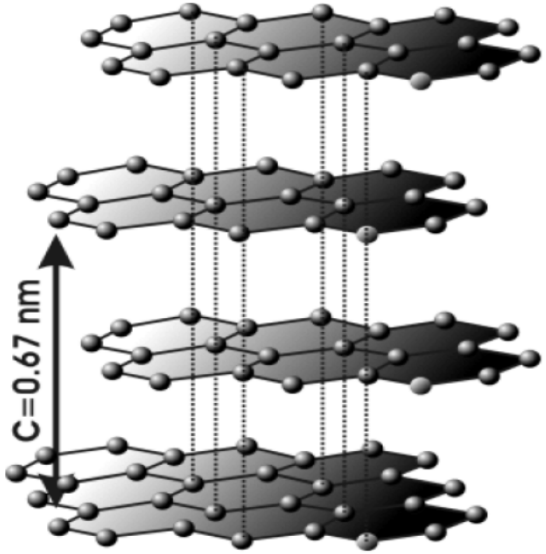
Carbon ($^6C=1s^2 2s^2 2p^2$, group IV)

2s, $2p_x$, $2p_y$ and $2p_z$ orbitals can mix with each other.

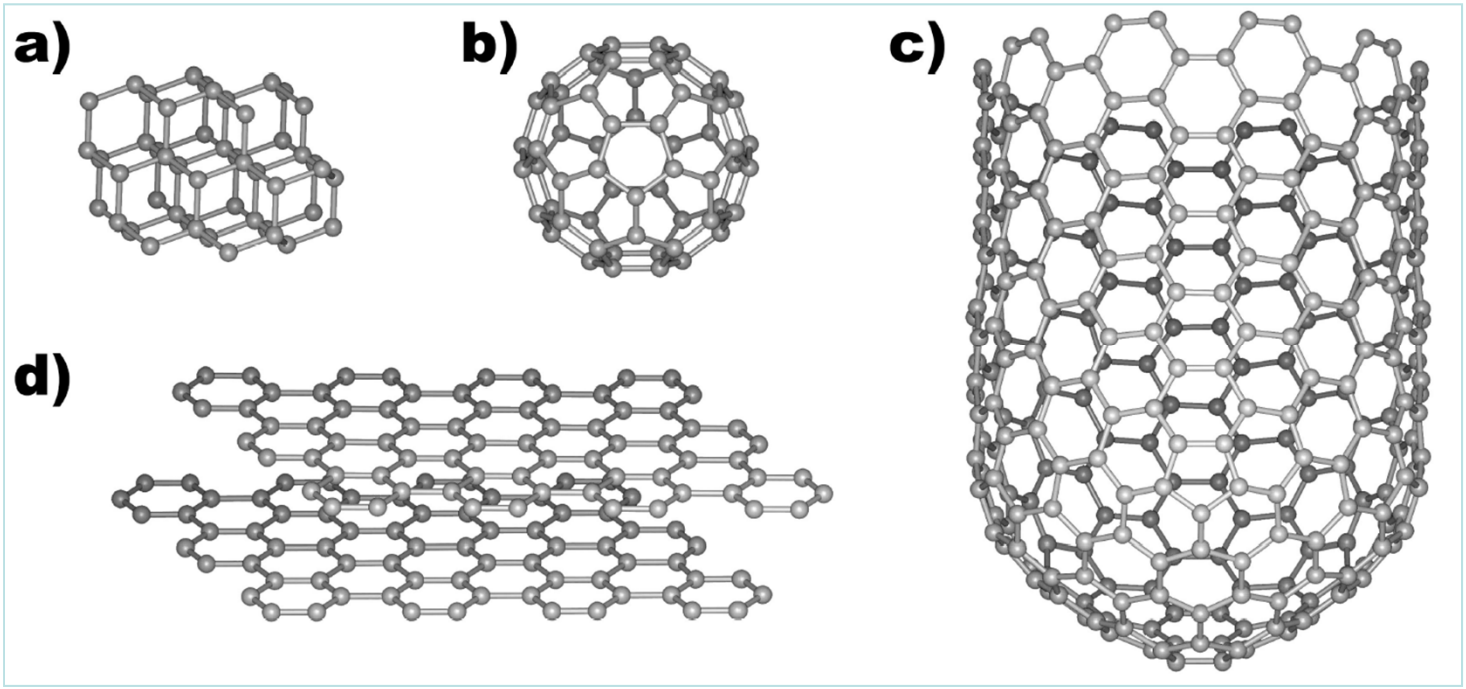
diamond : sp^3



graphite : sp^2+p_z



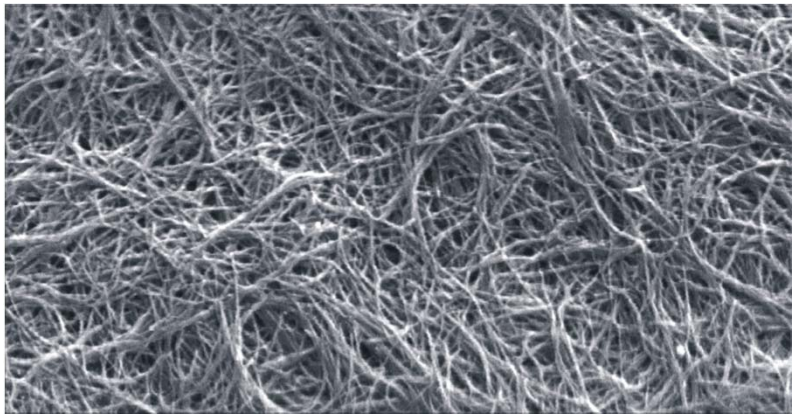
Different modifications of carbon



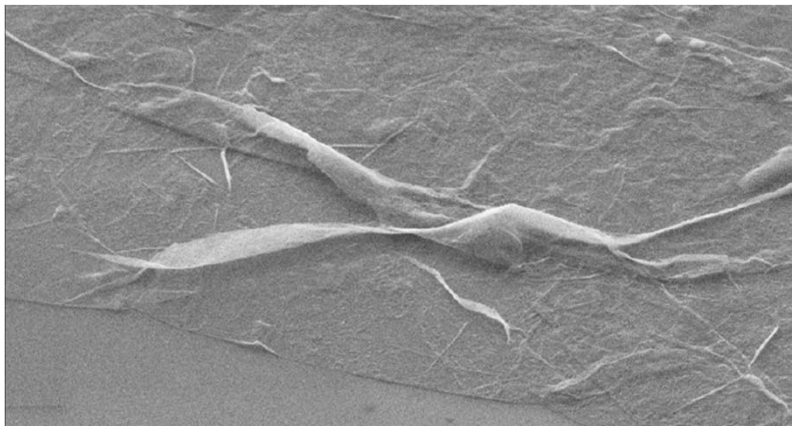
Danubia NanoTech, s.r.o.

Research in nanoscience and nanotechnology

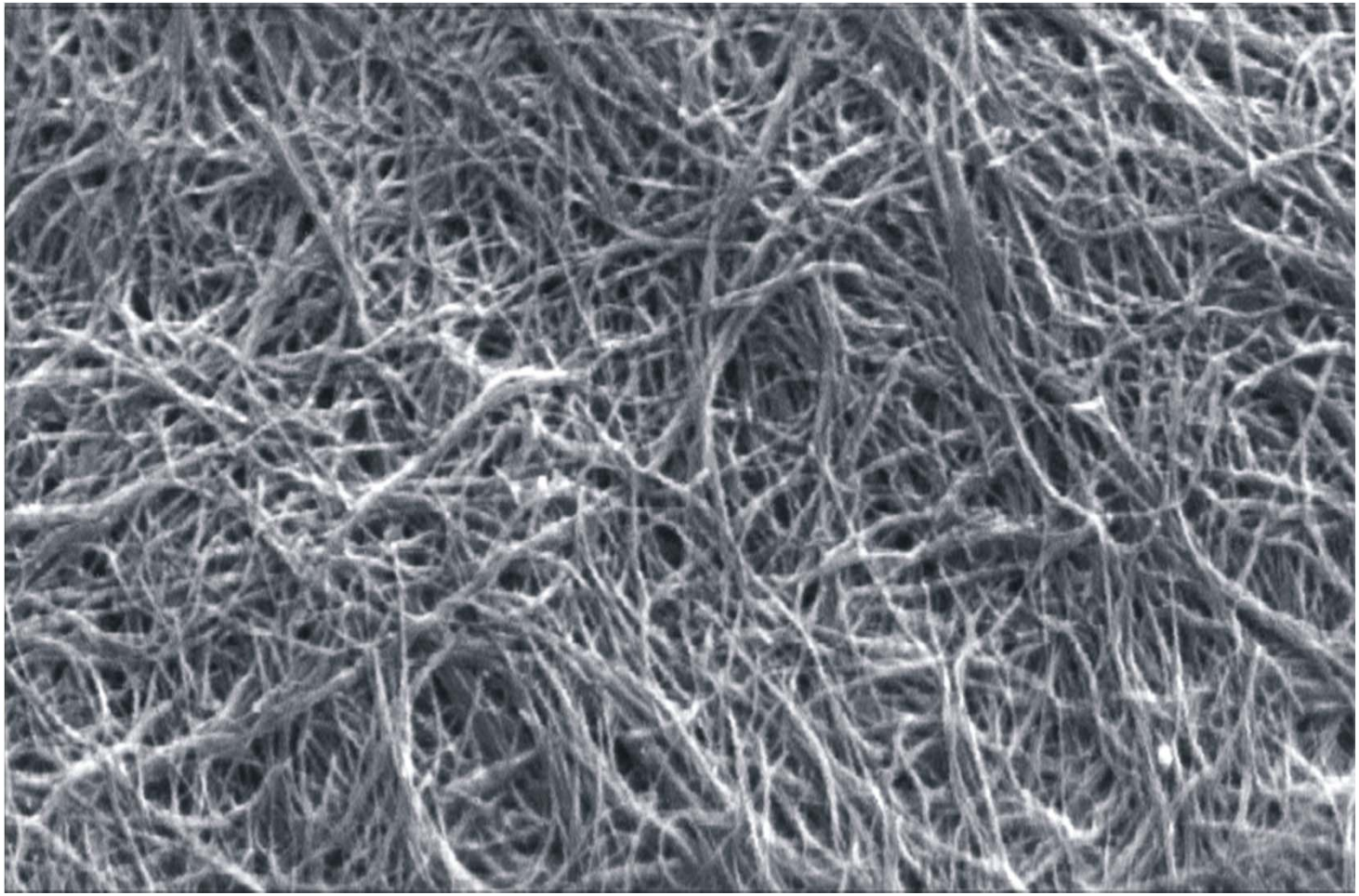
- **Production of Single Wall Carbon Nanotubes**
- **Research on SWNT**



- **Production of Few-Layer Graphene**
- **Research on Graphene**

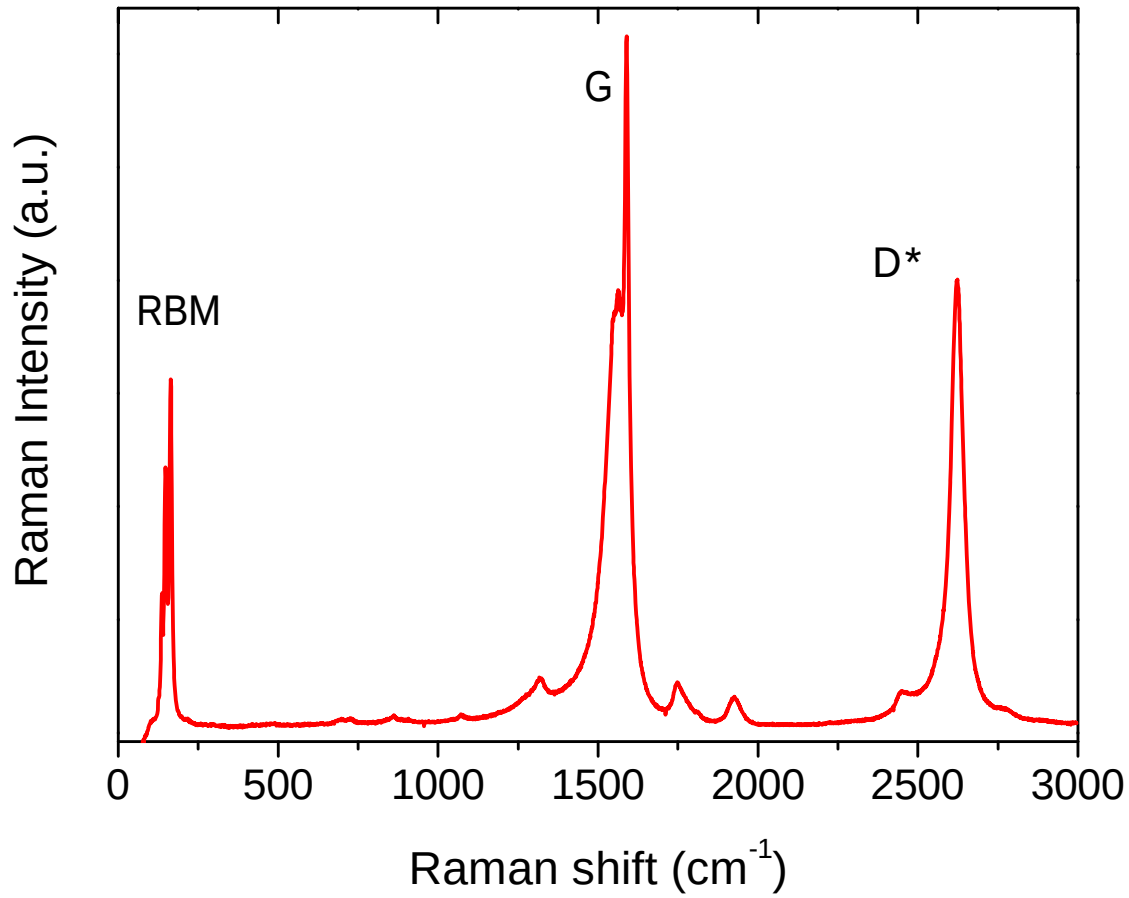


Defects in SWNTs

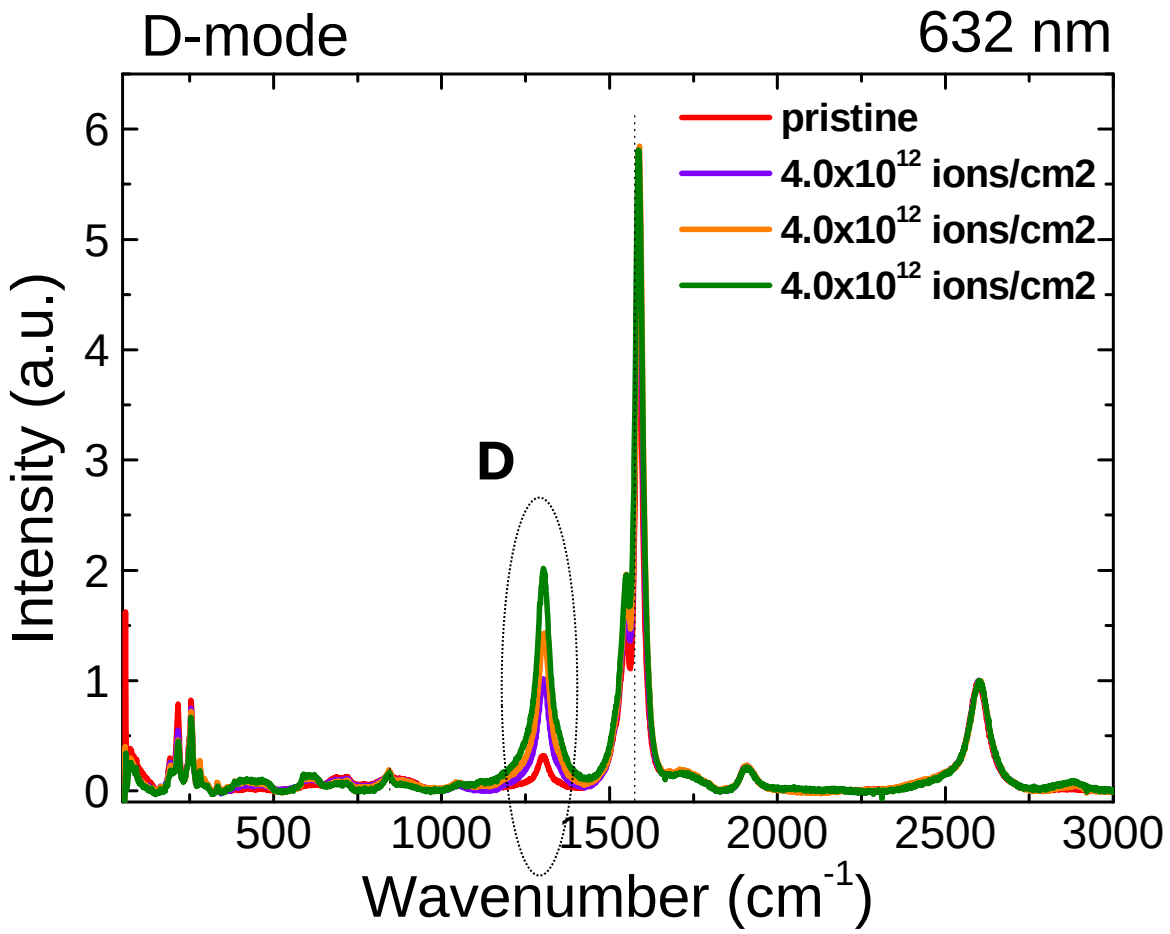


Raman specroscopy

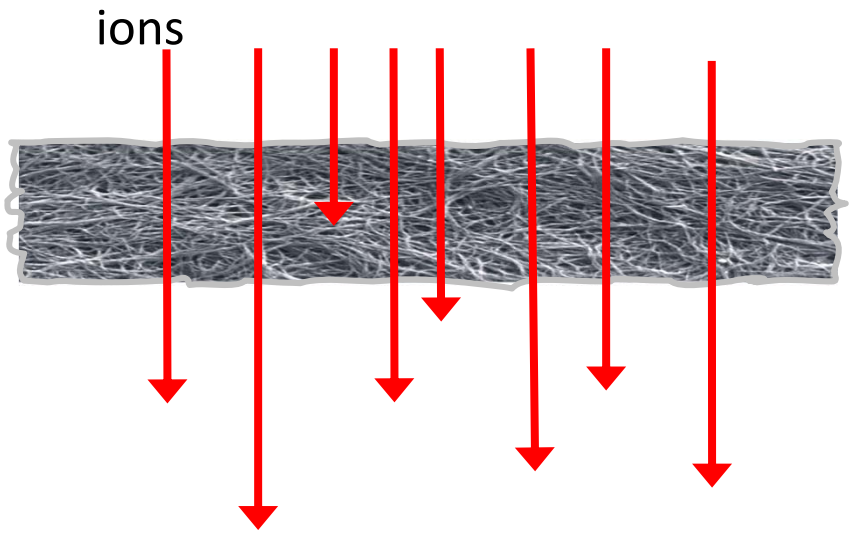
- inelastic photon scattering

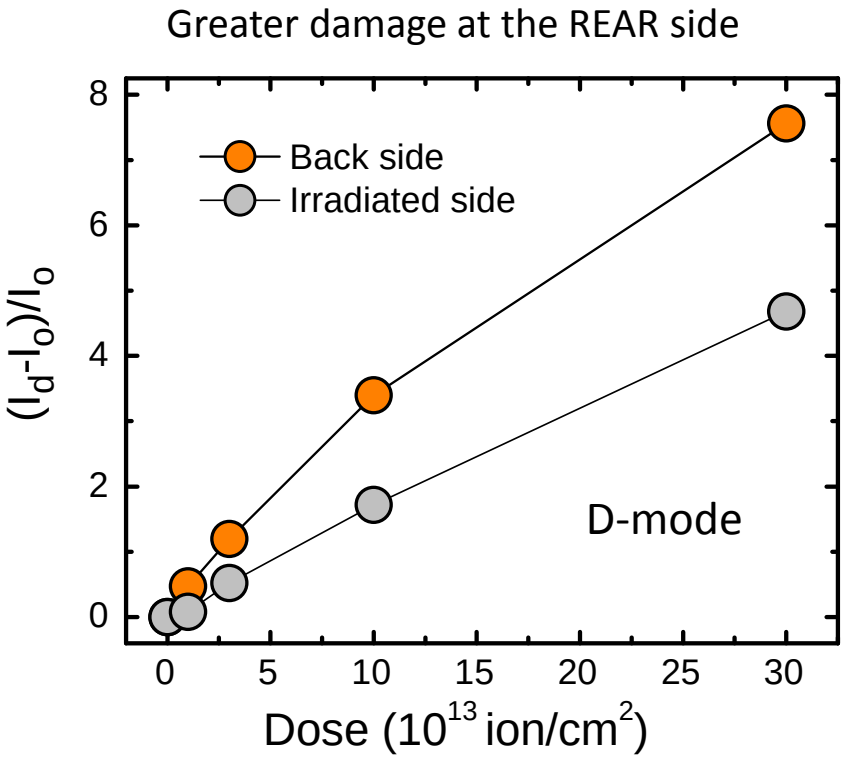


D-mode of Raman spectra increases with the Dose of Ar^+ ions



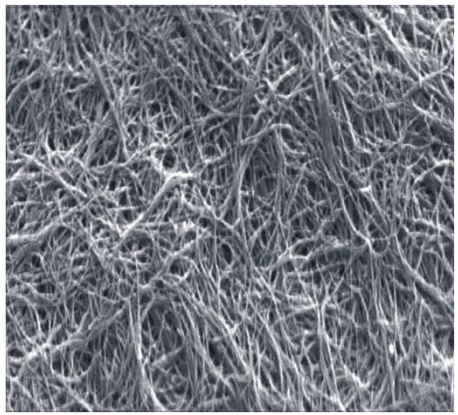
SWNT paper irradiated by 23 MeV C^{4+} ions



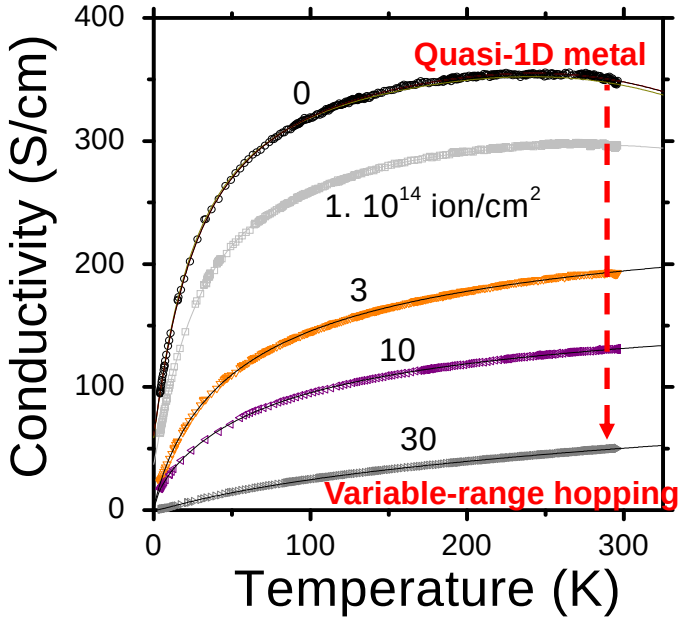


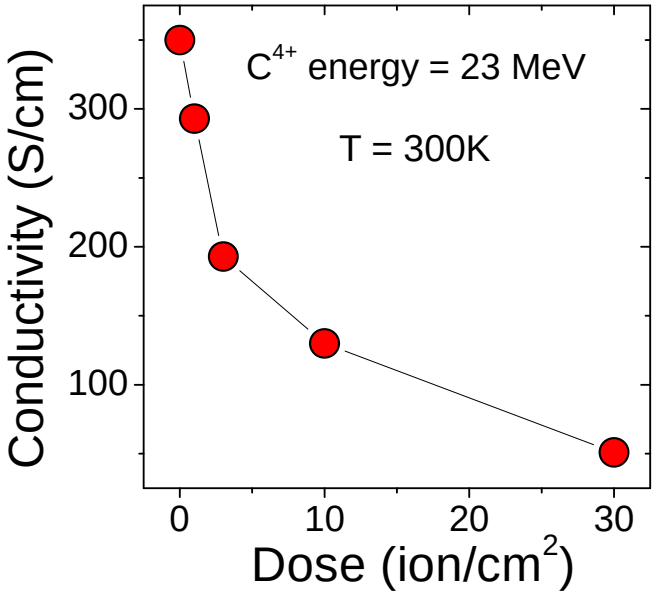
Skakalova, Kaiser, Detlaff, Arstila, Krashenninikov, Keinonen, Roth: Physica Status Solidi B, 245, (2008) 2280-2283

C^{4+}-irradiation of SWNT paper: *Electrical conductivity*

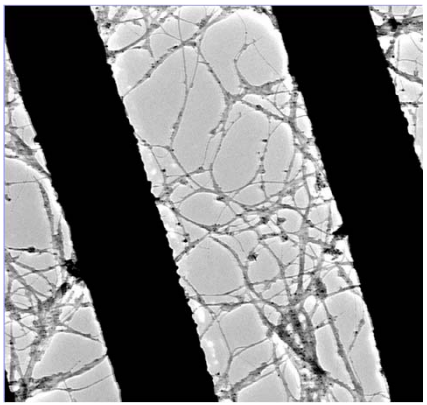


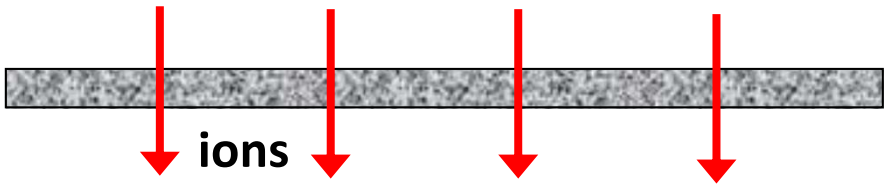
C^{4+}-energy = 23 MeV

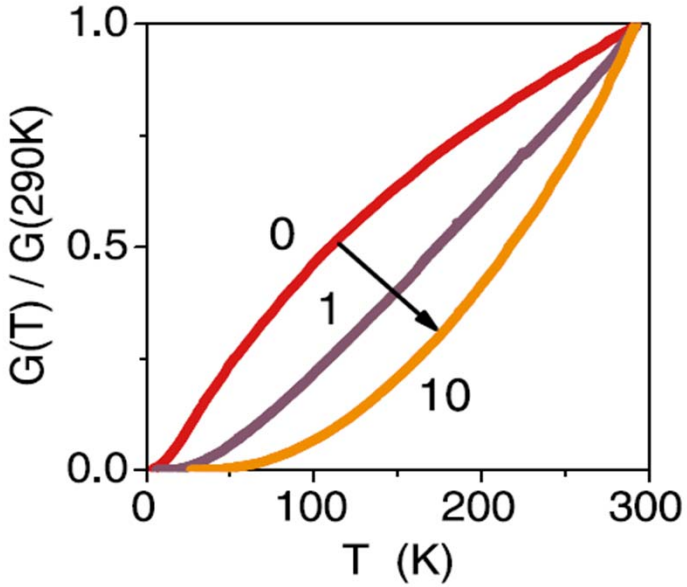


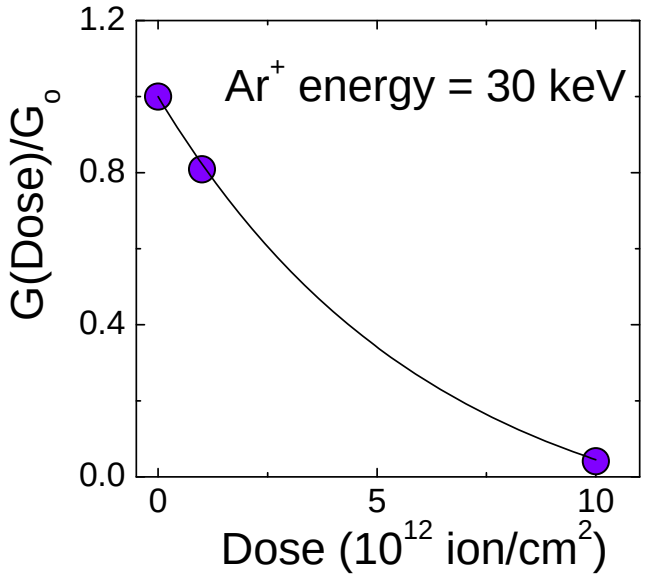


Electrical conductance of Ar^+ irradiated thin SWNT networks





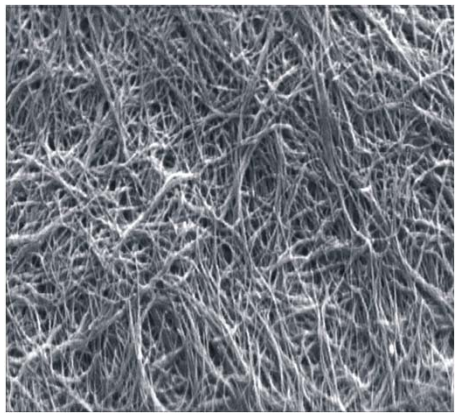


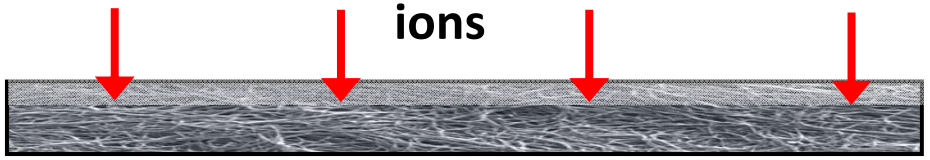


Variable-Range Hopping:

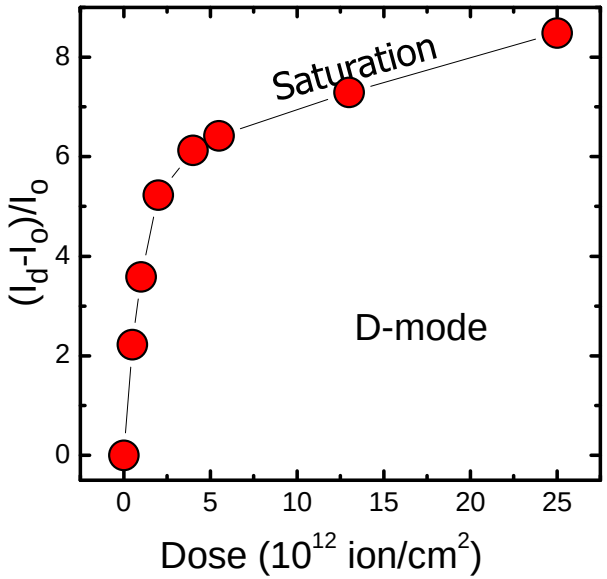
$$\sigma(T) = \sigma_0 \exp\left[-\left(\frac{T_0}{T}\right)^{1/(1+d)}\right]$$

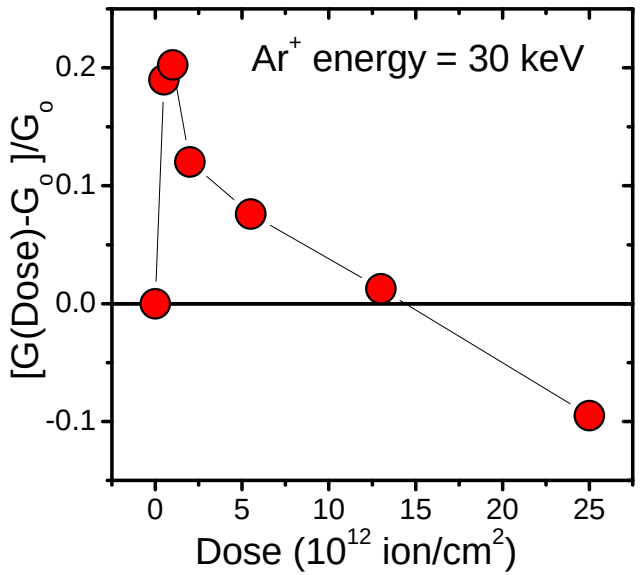
Surface penetration by 30 keV Ar^+ ions





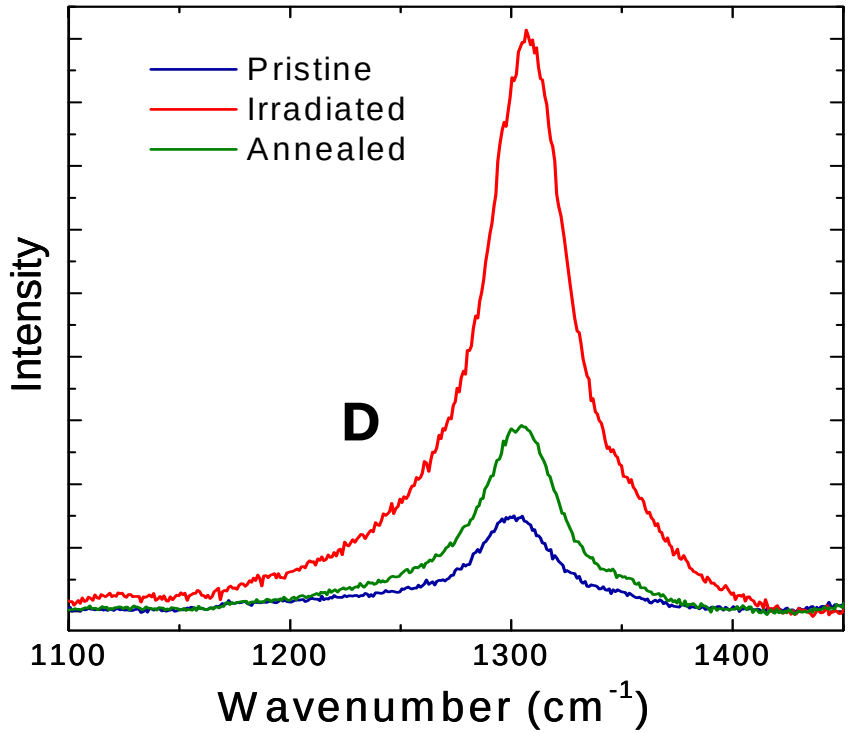
Dose effects of 30 keV Ar^+ ions





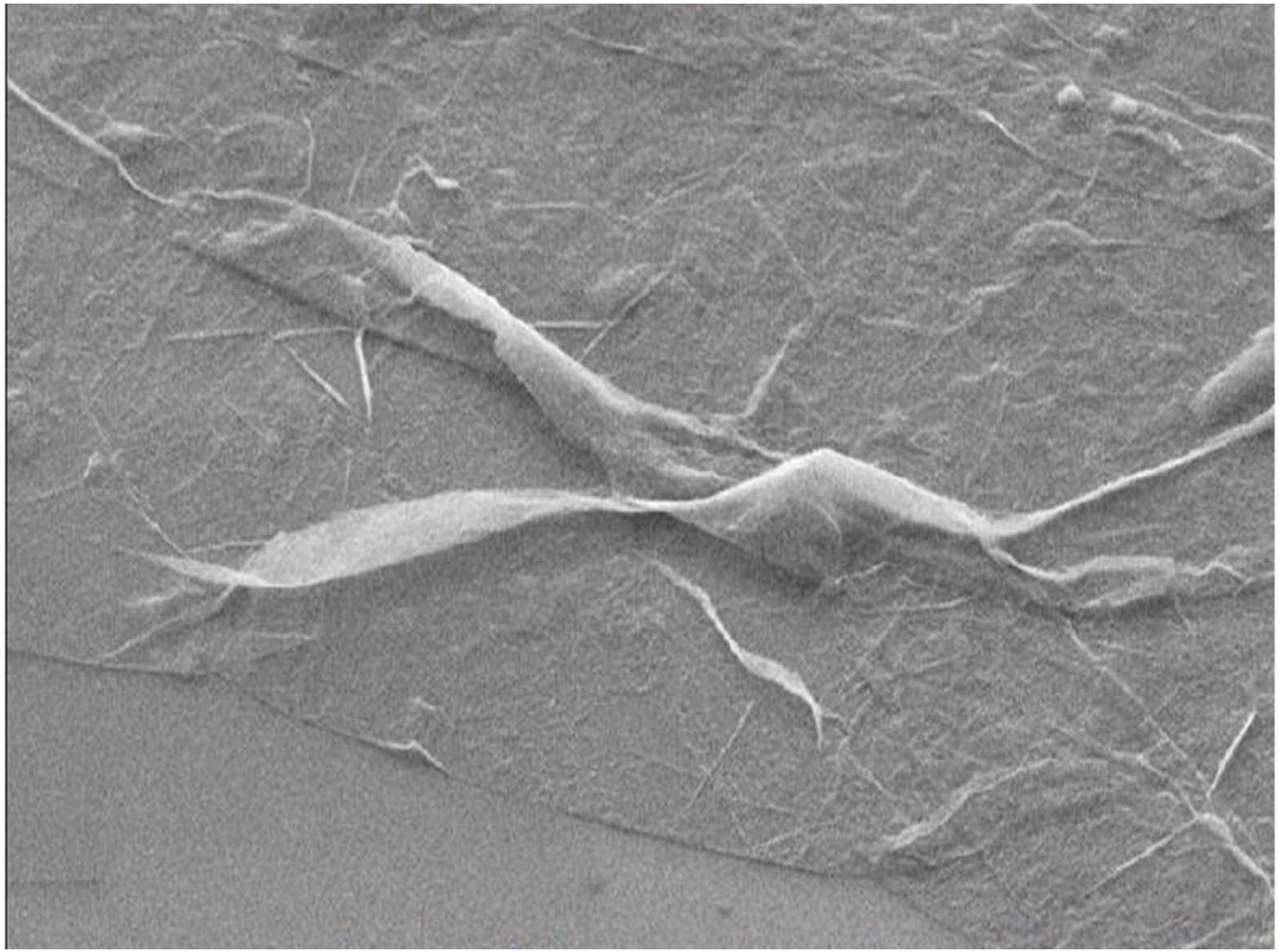
V. Skakalova, A.B. Kaiser, Z. Osvath, G. Vertesy, L.P. Biro, S. Roth, Appl. Phys. A 90, 597–602 (2008)

Effect of thermal annealing: Recovering structure of SWNTs



Viera Skákalová, Janina Maultzsch, Zoltán Osváth, László P. Biró, and Siegmar Roth,
Phys. Stat. Sol. (RRL) 1, No. 4, 138– 140 (2007)

Defects in Graphene

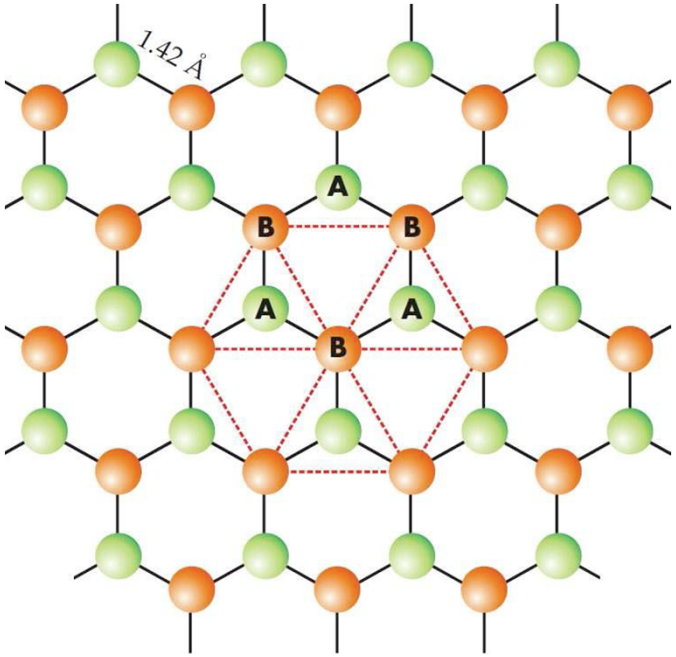


PHYSICAL REVIEW VOLUME 71, NUMBER 9 MAY 1, 1947

The Band Theory of Graphite

P. R. WALLACE*
National Research Council of Canada, Chalk River Laboratory, Chalk River, Ontario
(Received December 19, 1946)

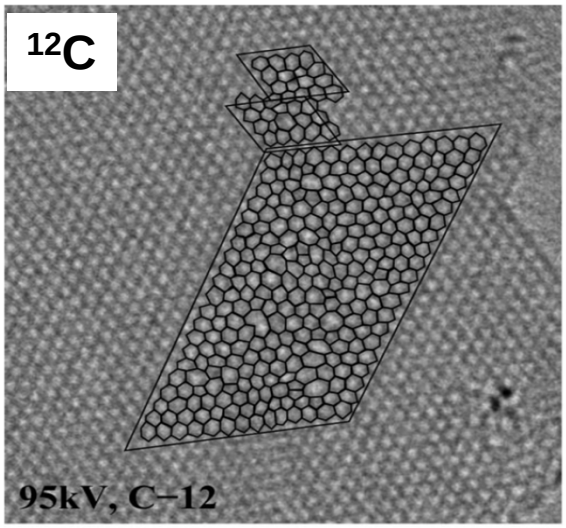
Hexagonal crystal structure of graphene



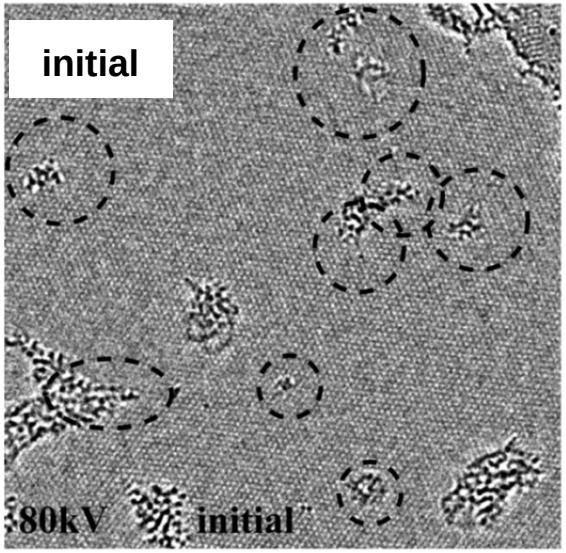
Two equivalent sub-lattices A and B

TEM study of electron irradiation: ^{12}C vs ^{13}C

Direct knock-on damage: Energy = 95 keV, Dose of 1.4 x 10^9 e/nm^2

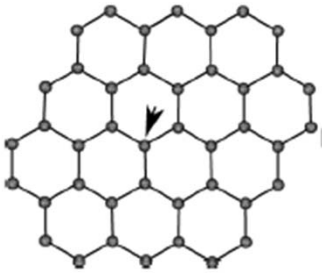


Damage induced by contamination



Jannik C. Meyer, et al. , PHYSICAL REVIEW LETTER 108, 196102 (2012)

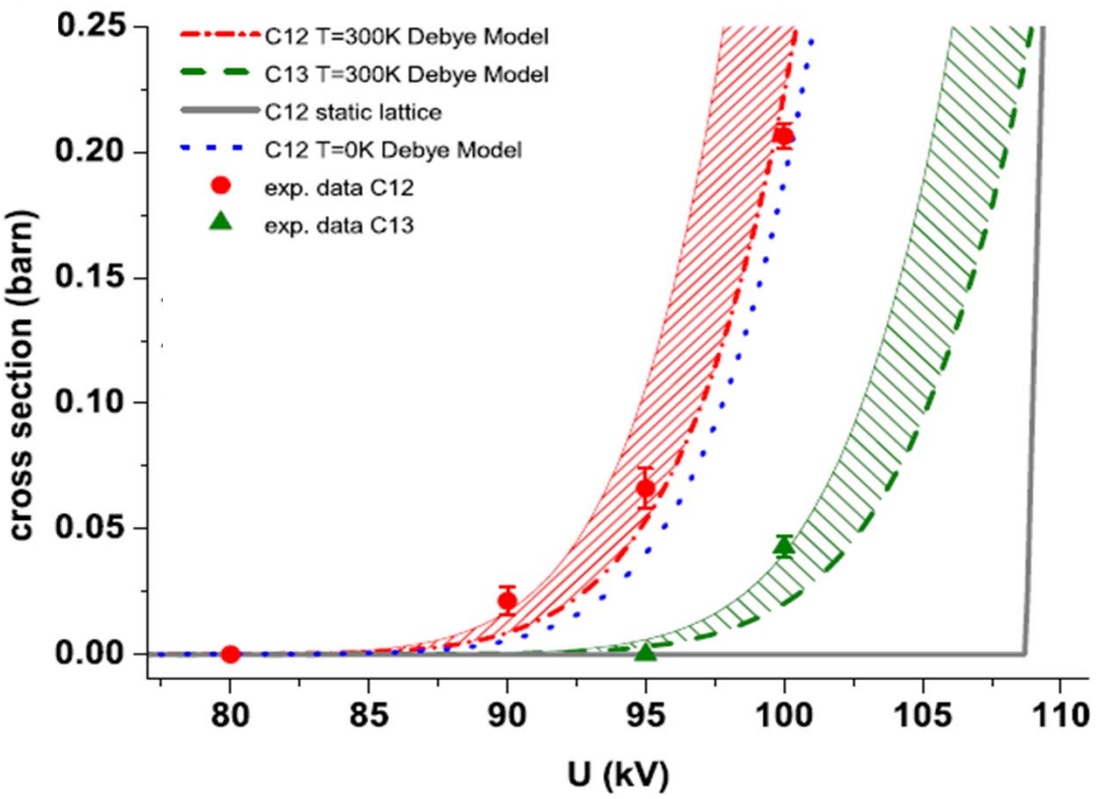
Measured and calculated knock-on displacement cross sections.



Monovacancy: dangling bond with a much lower emission threshold. Subsequent sputtering of this atom may double the cross section.

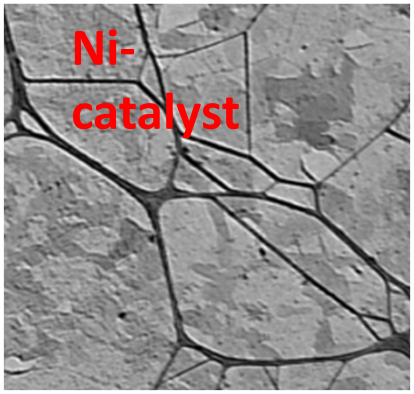
The lower boundary of the shaded areas correspond to the calculated cross section.

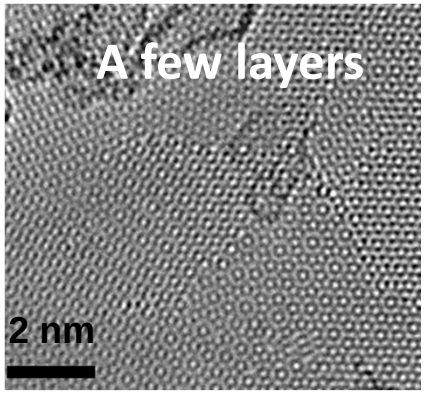
The upper boundary is twice the calculated value
(expected for correlated sputtering).

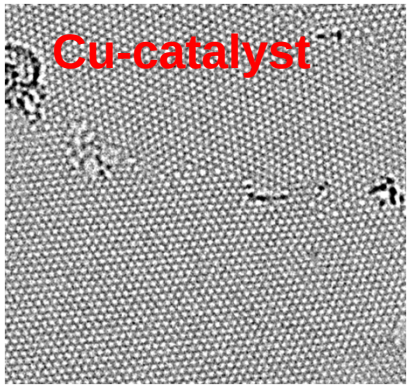


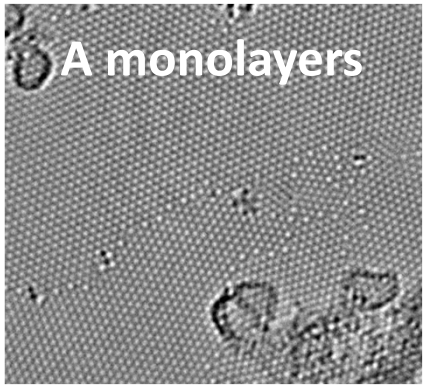
Jannik C. Meyer, et al. , PHYSICAL REVIEW LETTER 108, 196102 (2012)

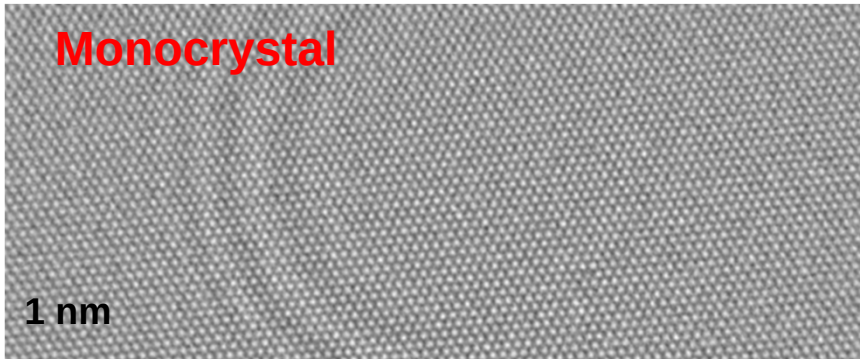
Temperature dependences of conductance





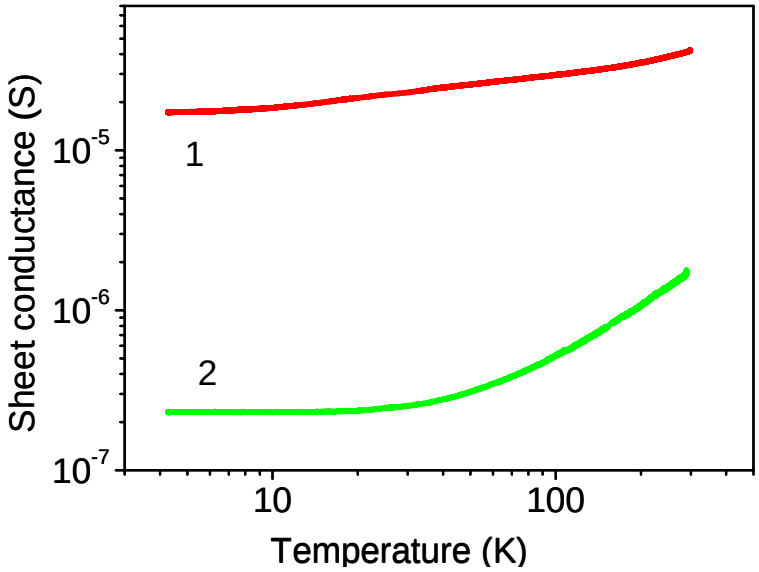


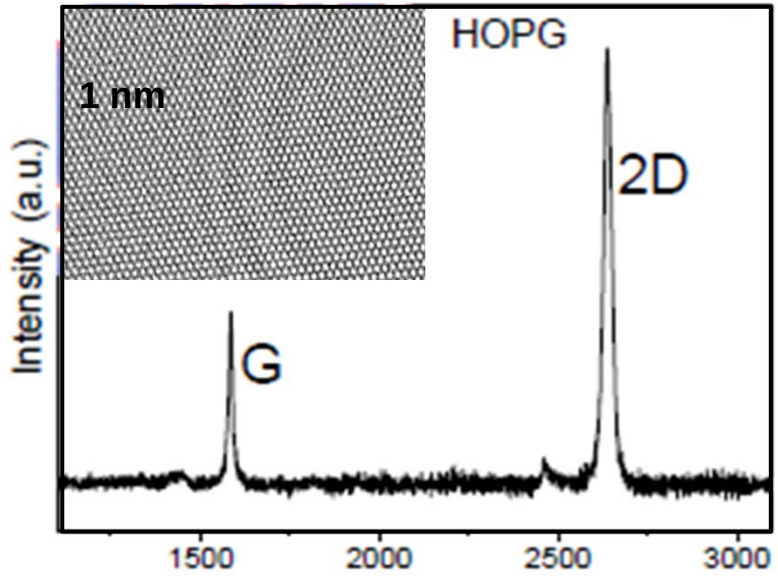


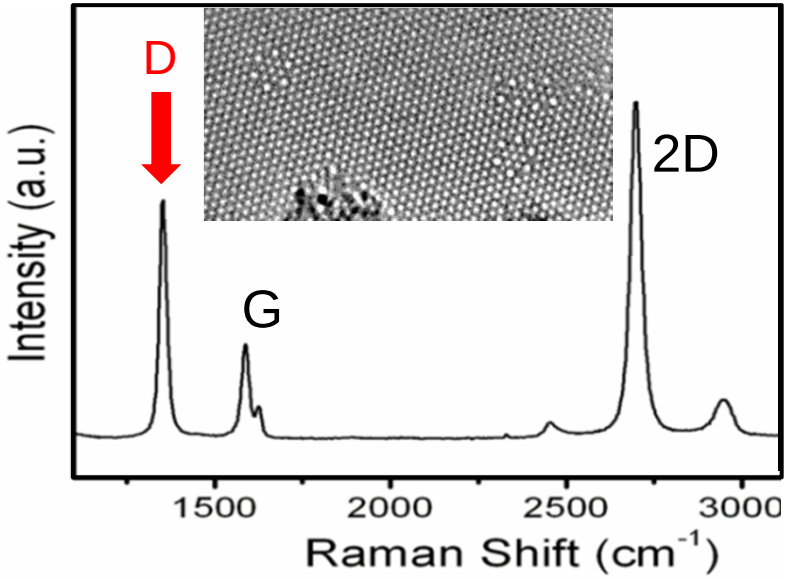


Defects formed in presence of ammonia

1. pristine CVD-monolayer
2. N-doped CVD-monolayer







H. J. Park, V. Skákalová, T. Iwasaki, J. C. Meyer, U. Kaiser and S. Roth, **Physica Status Solidi B, 247(2010)2915-2919**

Chemical Oxidation-Reduction of Graphite

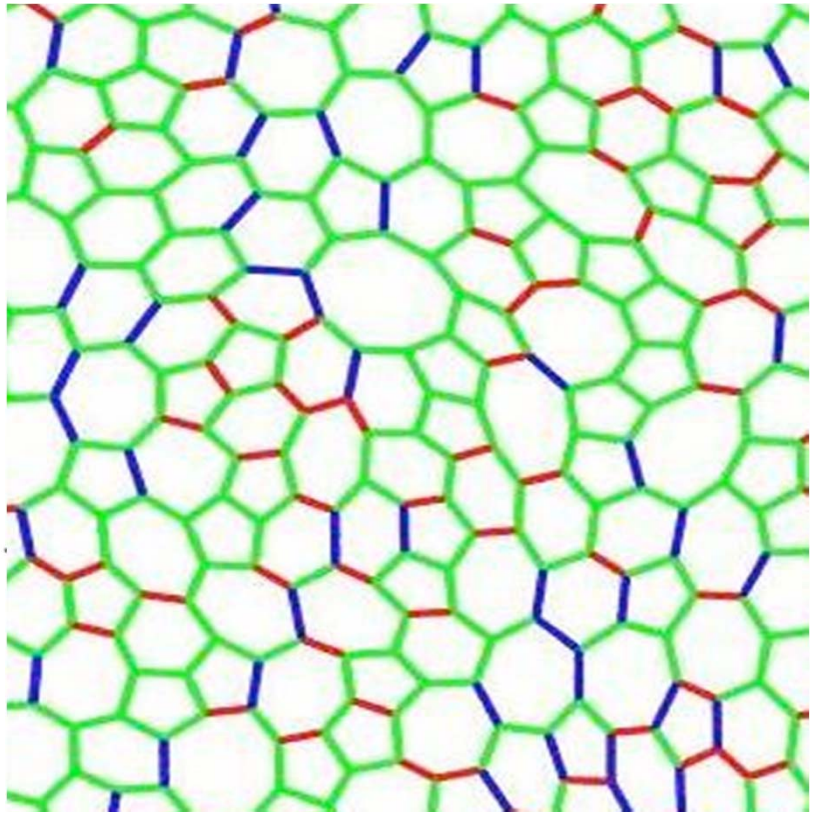
Graphite oxide was first prepared by Oxford chemist Benjamin C. Brodie in 1859

Oxidation introduces functional groups:

A: Epoxy bridges

B: Hydroxyl groups

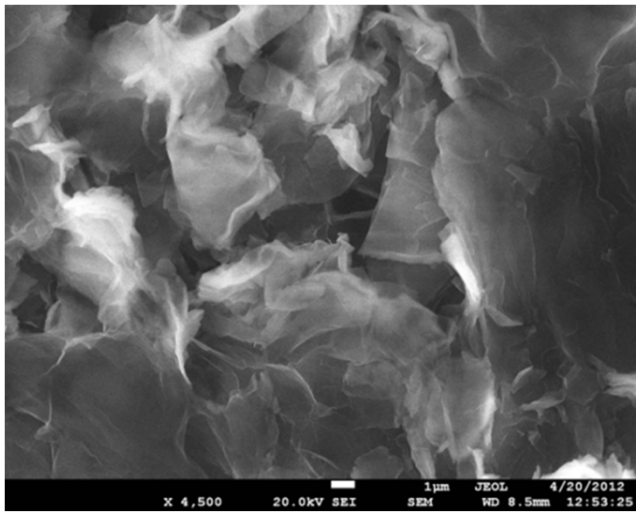
C: Pairwise carboxyl groups

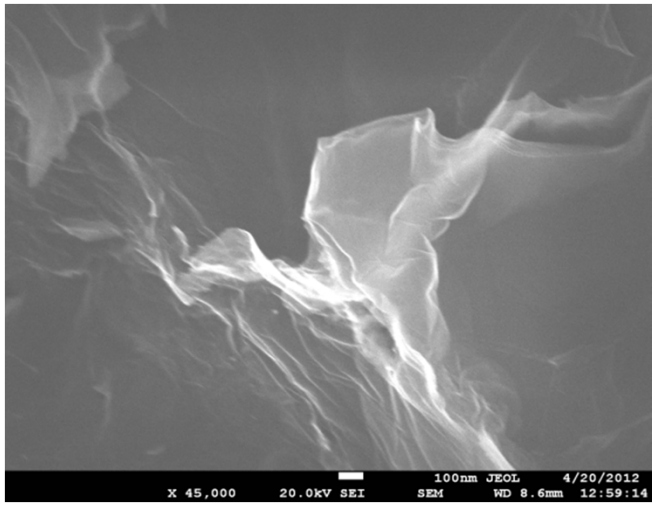


Reduction removes functional groups

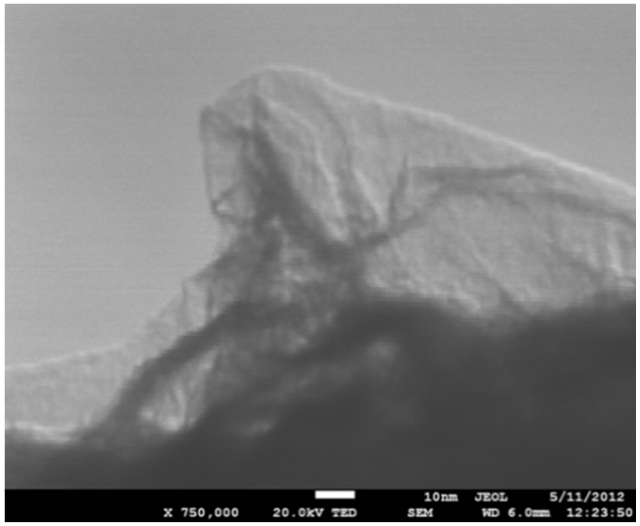
- Restores sp^2 orbitals
- Leaves many structural defects

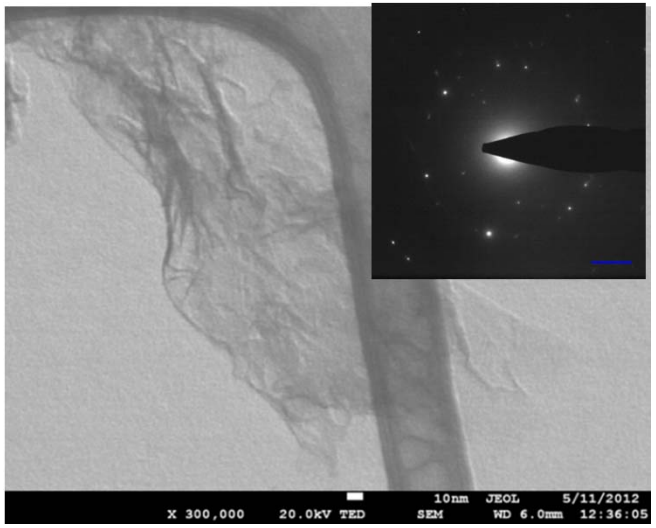
Microscopic characterization of thermally reduced Graphite Oxide (rGO)





SEM of GO flakes (Hummers)

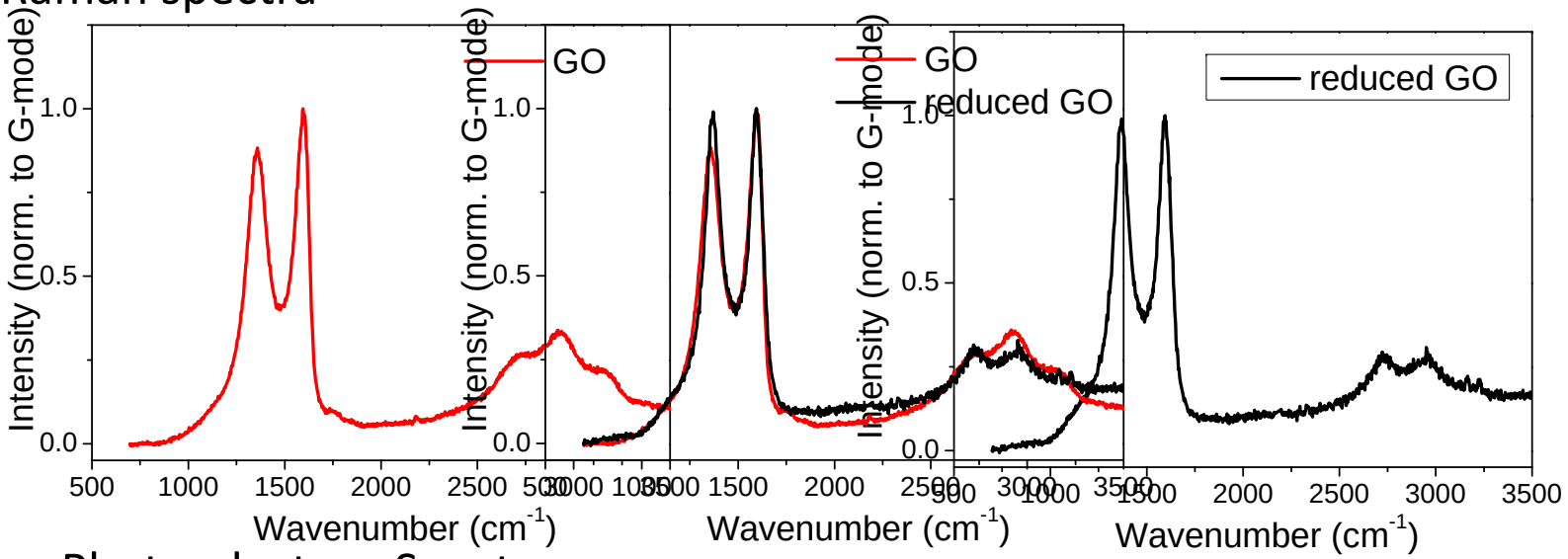




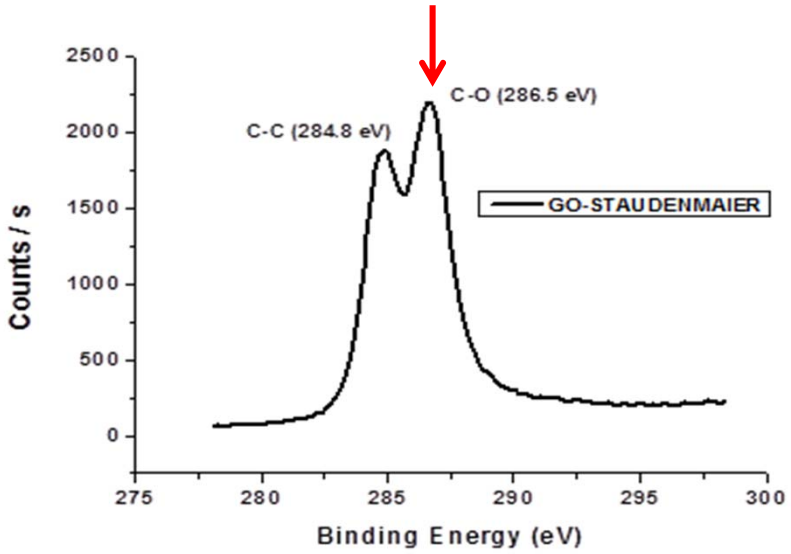
STEM of reduced GO

Spectroscopic characterization of thermally reduced Graphite Oxide (rGO)

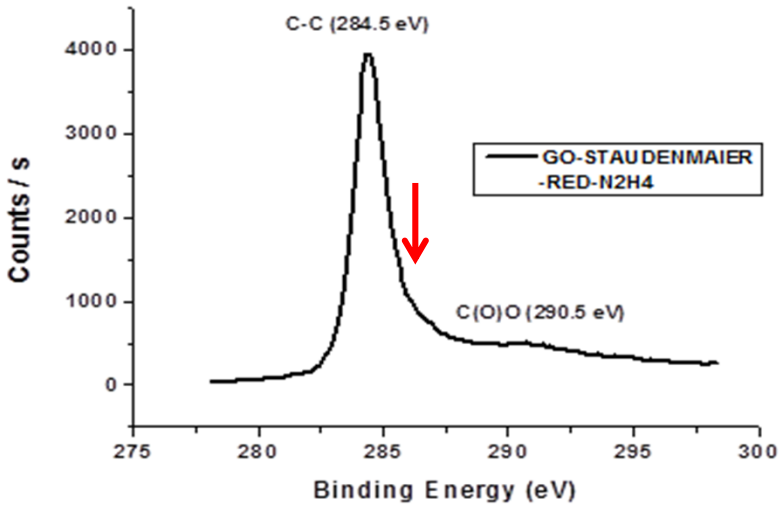
Raman spectra



X-ray Photo-electron Spectra

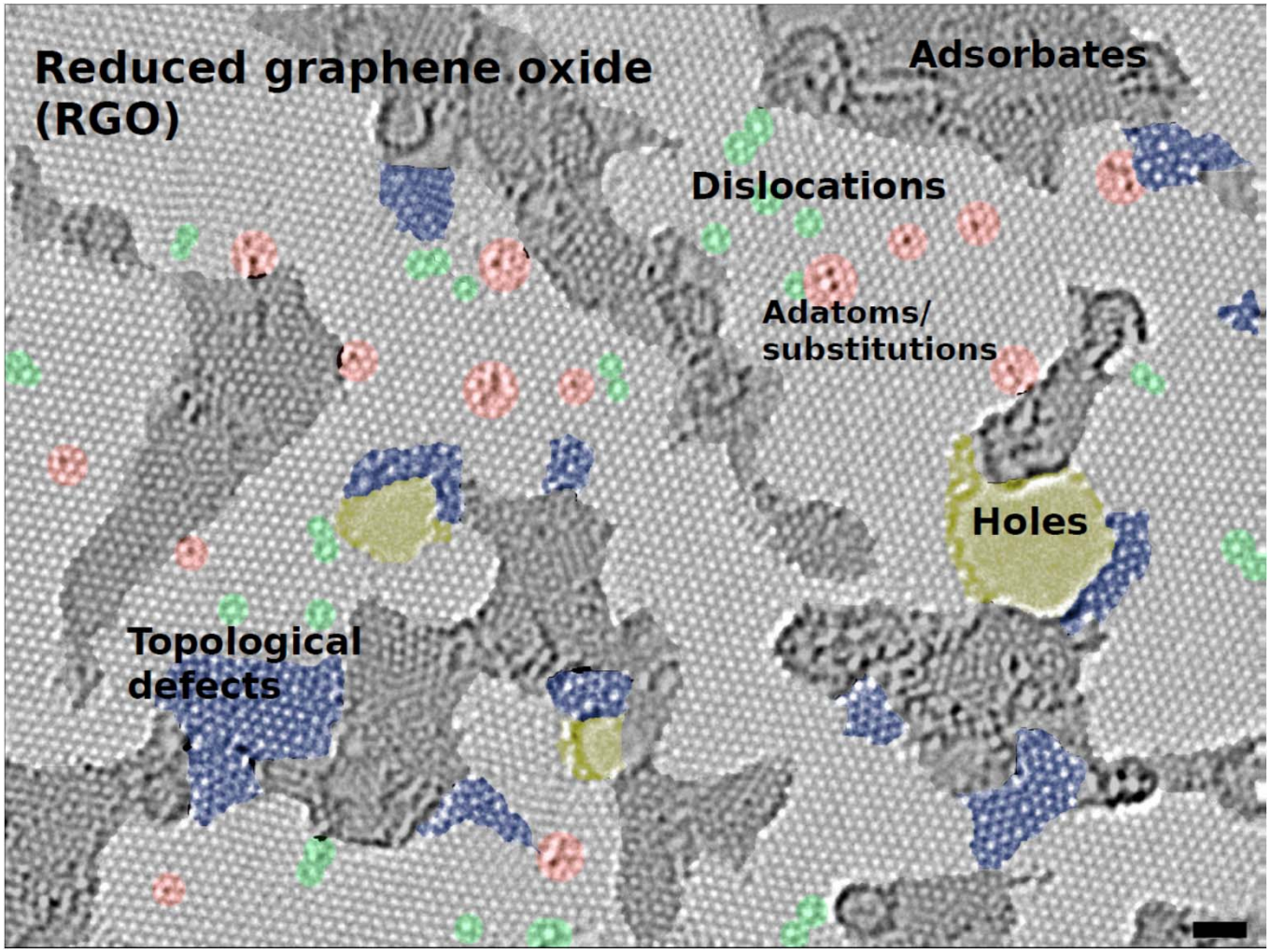


Thorough removal of oxide groups



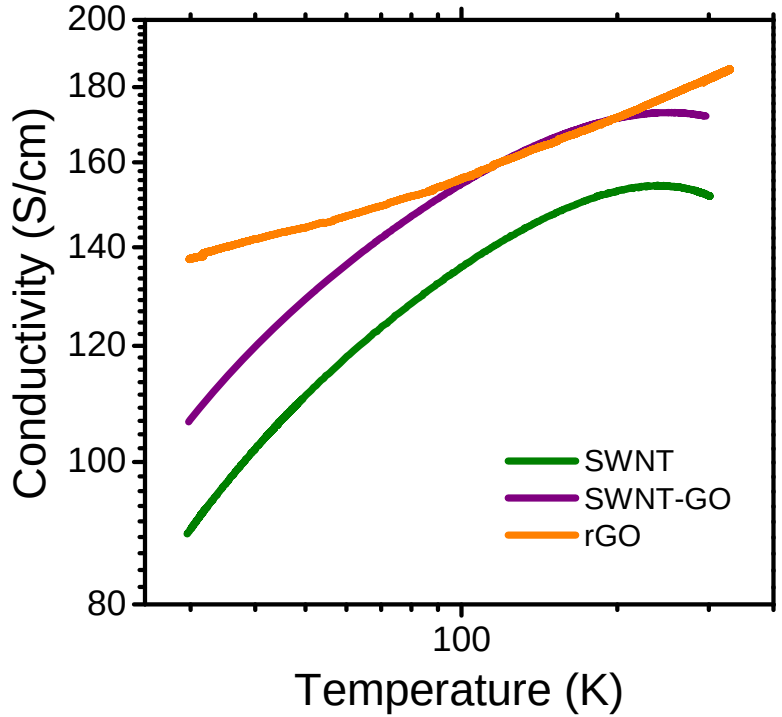
Microscopic characterization of thermally reduced Graphite Oxide (rGO)

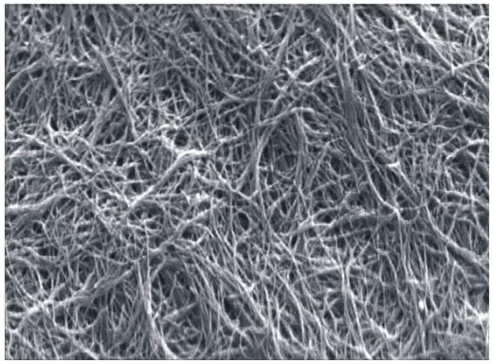
HR TEM: Jannik Meyer, Uni Ulm

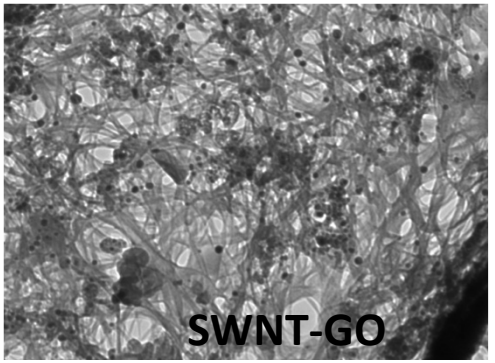


Electrical conductivity of thermally reduced Graphite Oxide (rGO)

In comparison with SWNT and SWNT-GO composite







- The electrical conductivity of SWNT-GO composite higher than that of SWNT
- Identical electron transport mechanism (Fluctuation Assisted Tunnelling) in SWNT-GO composite and SWNT paper
- Very high electrical conductivity in rGO film with metallic electron transport

Summary

SWNT networks:

- Ion irradiation damages the structure and lowers electrical conductivity
- Thermal annealing removes defects in the SWNT structure

Graphene: A structural damage affects severaly electronic transport

Graphite oxide: Non conductive and transparent. Electrical and optical properties tunable by reduction of the oxide groups.

Reduced graphite oxide:

Metallic character of electron transport

Composite SWNT-GO:

The same mechanism of electron transport like in SWNT film

Composite SWNT-reduced GO:

?????????????? Under investigation.

Aknowledgment

The results have been acquired within several years of collaboration between

Max Planck Institute in Stuttgart

Danubia NanoTech (SME) in Bratislava

and

University of Vienna

Thanks for attention ☺

SWNT networks