High-energy ion irradiation of carbon nanostructures and degree of damage characterisation

Michalina Milewicz-Zalewska

Joint Institute for Nuclear Research in Dubna (Russia), Flerov Laboratory of Nuclear Reactions

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Outline

- High energy ions irradiation - how high?
- Carbon nanostructures - which exactly?
- Degree of damage - indicated by what?
- Characterisation - by what methods?
- Summary
- Acknowledgements
- References

High-energy ion irradiation

- Energies in the range of MeV - Xe 167 MeV
- IC-100 cyclotron - FLNR, JINR, Dubna
- Doses from 10^{12}, $6*10^{12}$ and 10^{13} ions/cm ^{2} and reference sample (non irradiated)

[1]

Carbon nanostructures

- Fullerenes, nanodiamonds, nano-onions etc.
- Nanotubes: single-walled, double-walled, multi-walled
- Graphene, graphene oxide

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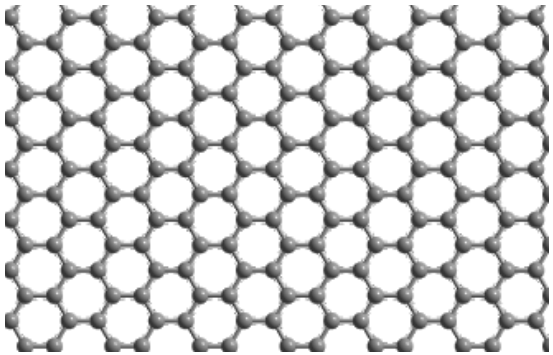
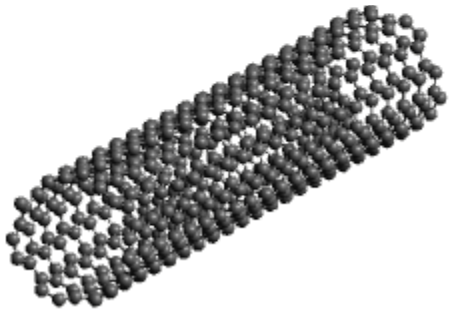
Carbon nanostructures

GRAPHENE

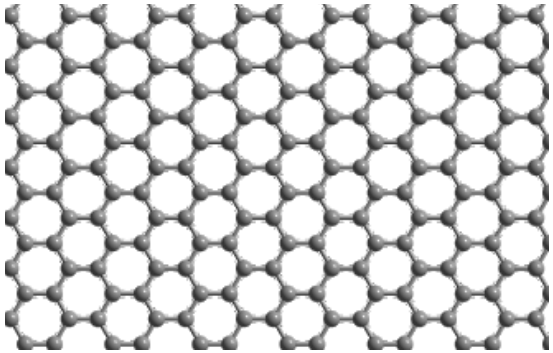


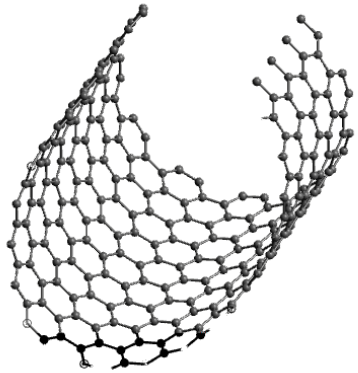
SINGLE-WALLED CARBON NANOTUBES (SWNT)

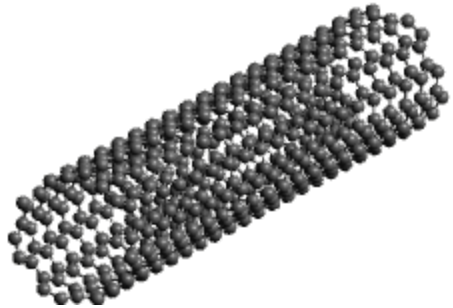


Carbon nanostructures

GRAPHENE → SWNT

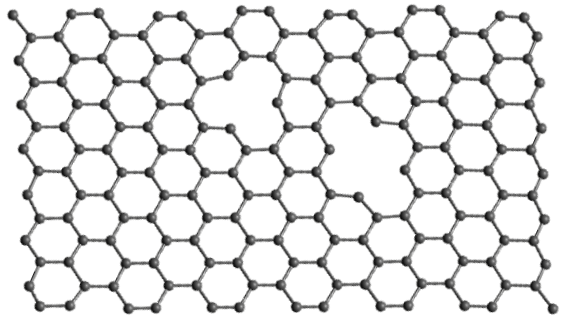




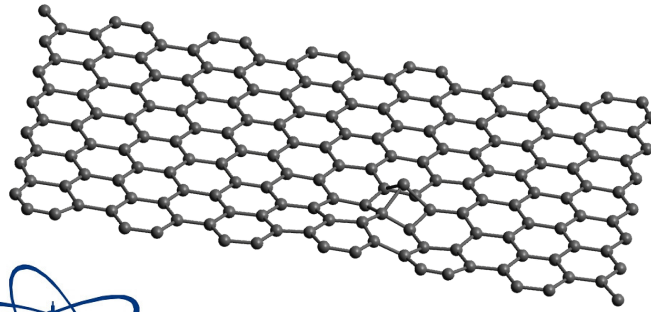


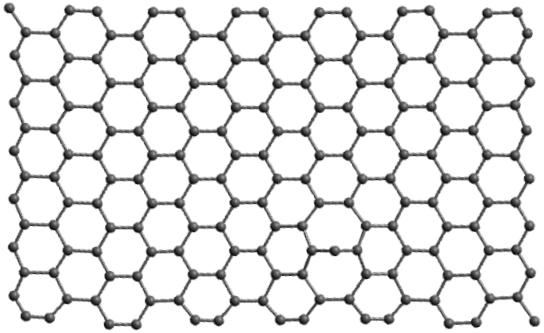
Degree of damage - defects

Vacancies: single, double etc.



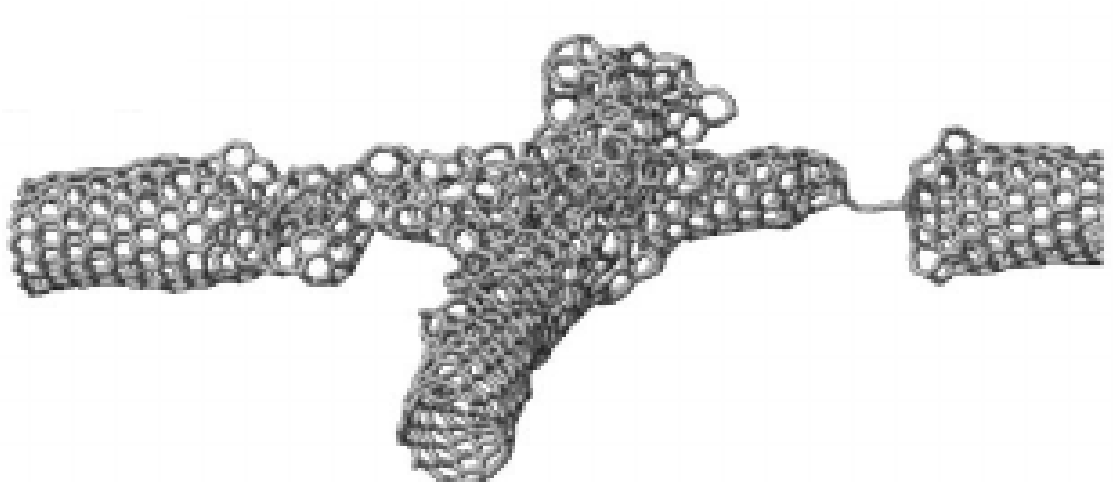
Ad-atoms, interstitials





Degree of damage

Yelding, amorphisation etc.



[2]

Damage indicators

- Visible damage
- Changes in properties - conductivity etc.
- Changes in vibrational modes (changes in geometry of structures)

Damage measurements

- Properties measurements - conductivity etc.
- Microscopy - Atomic Force (AFM), Scanning Tunneling (STM)
- Spectroscopy - Raman, infrared (IR)

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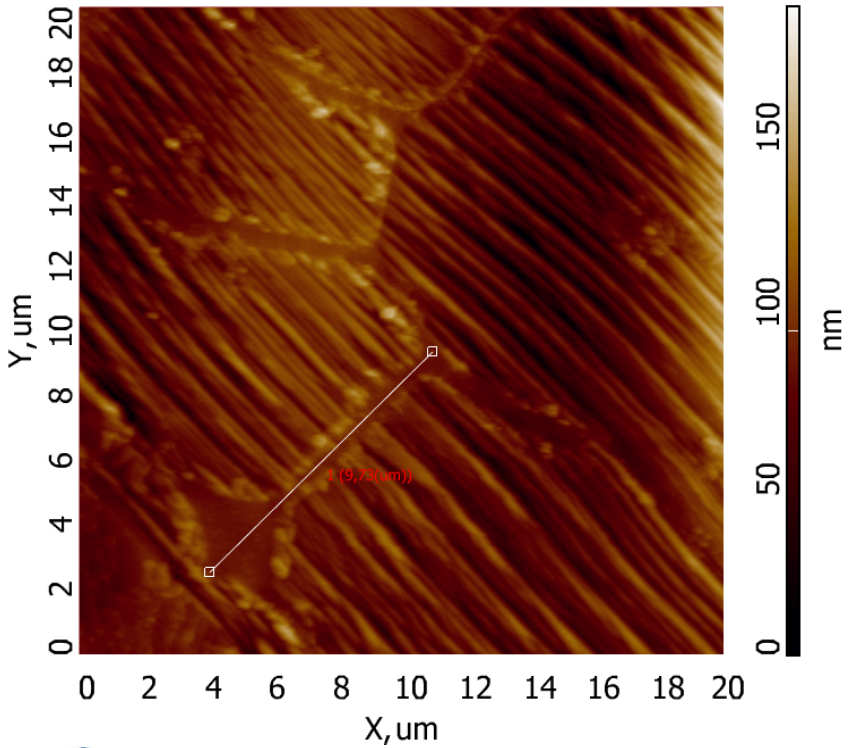
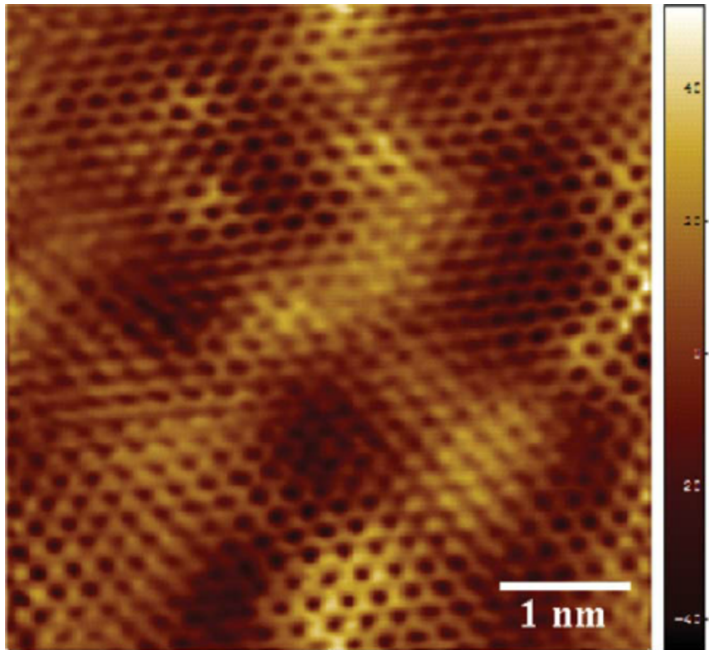
Microscopy

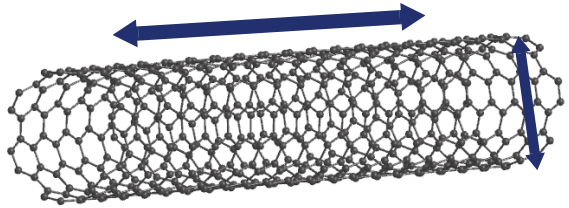
AFM, STM



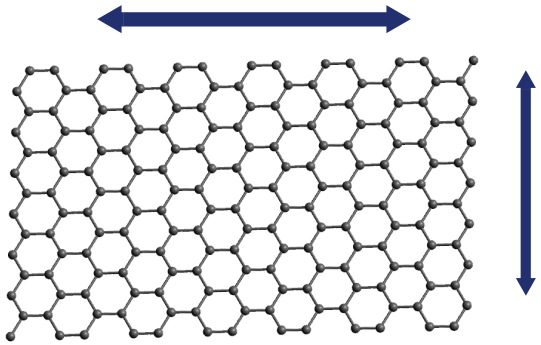


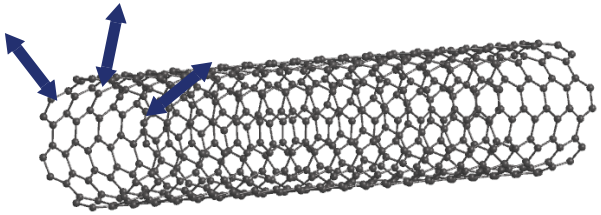
[3]

Raman spectroscopy

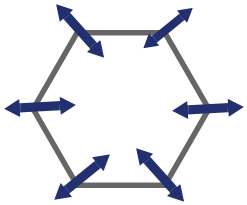


G band

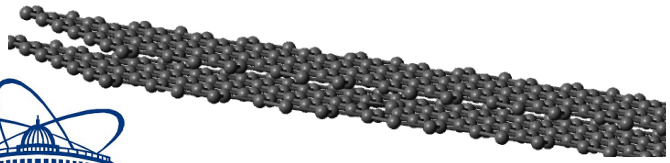




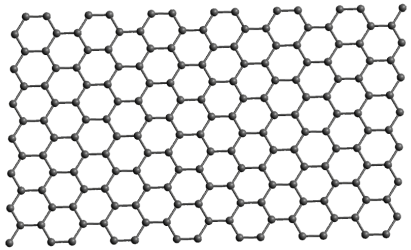
RBM band



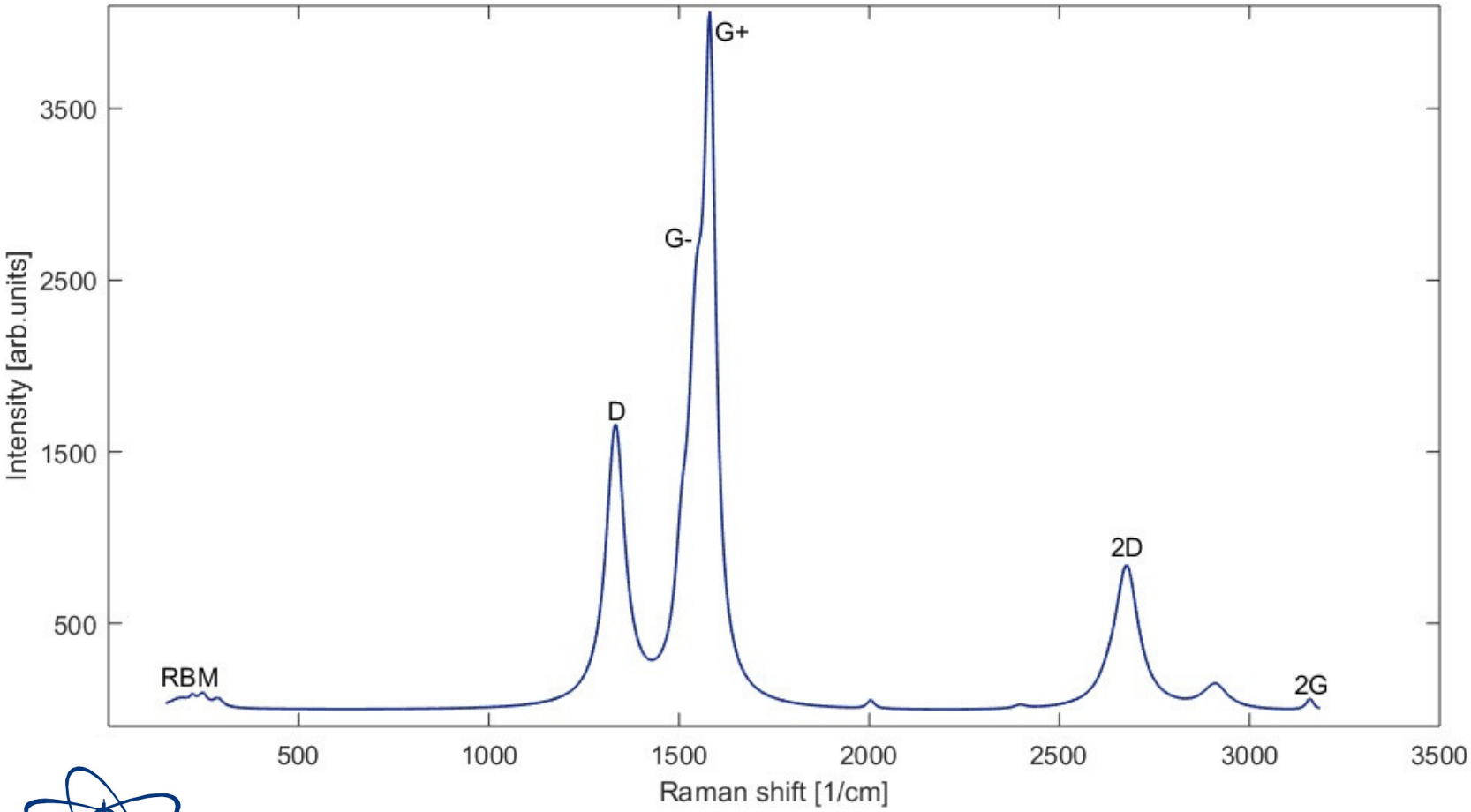
D band - ring breathing mode
with defects



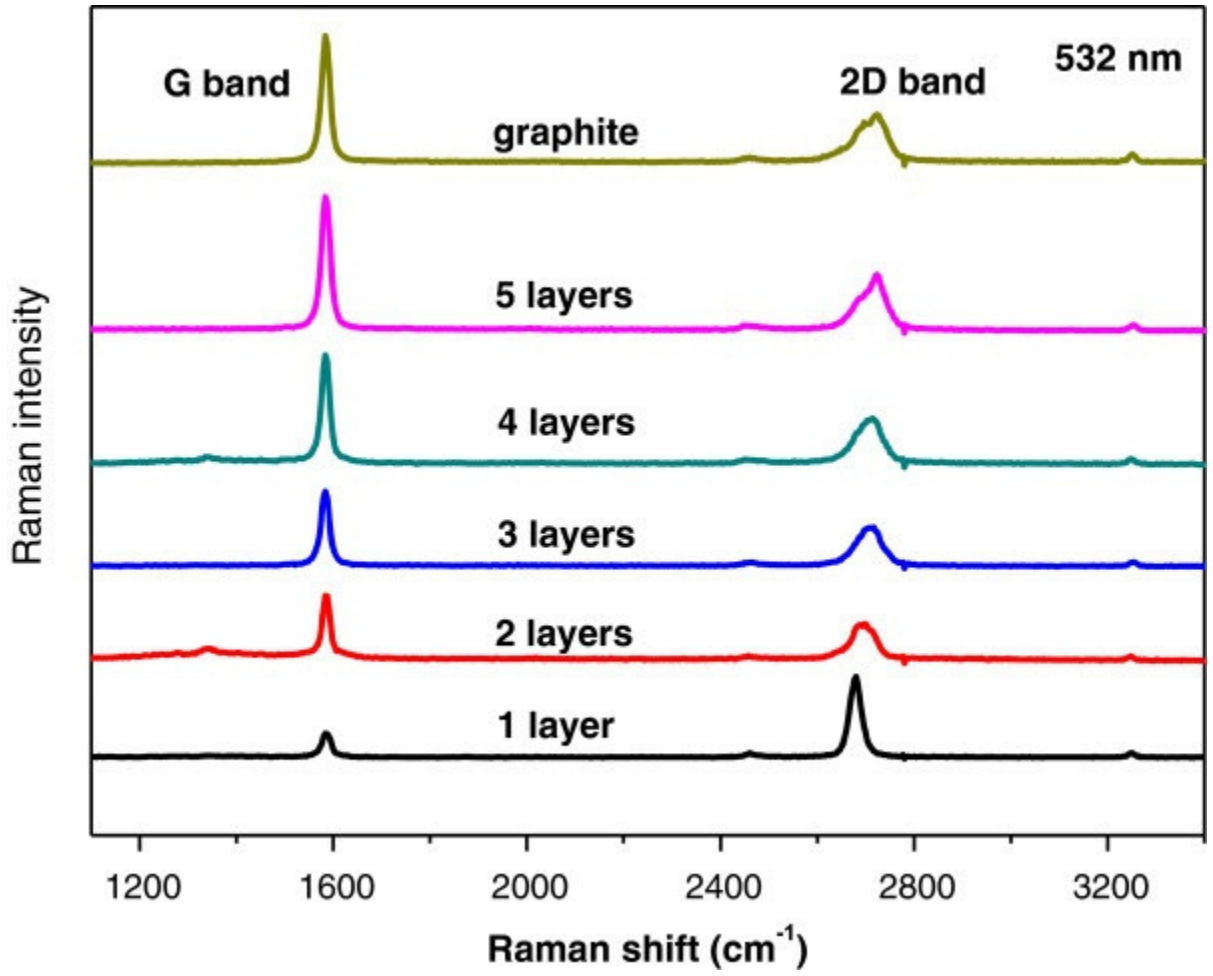
2D band



Raman spectroscopy



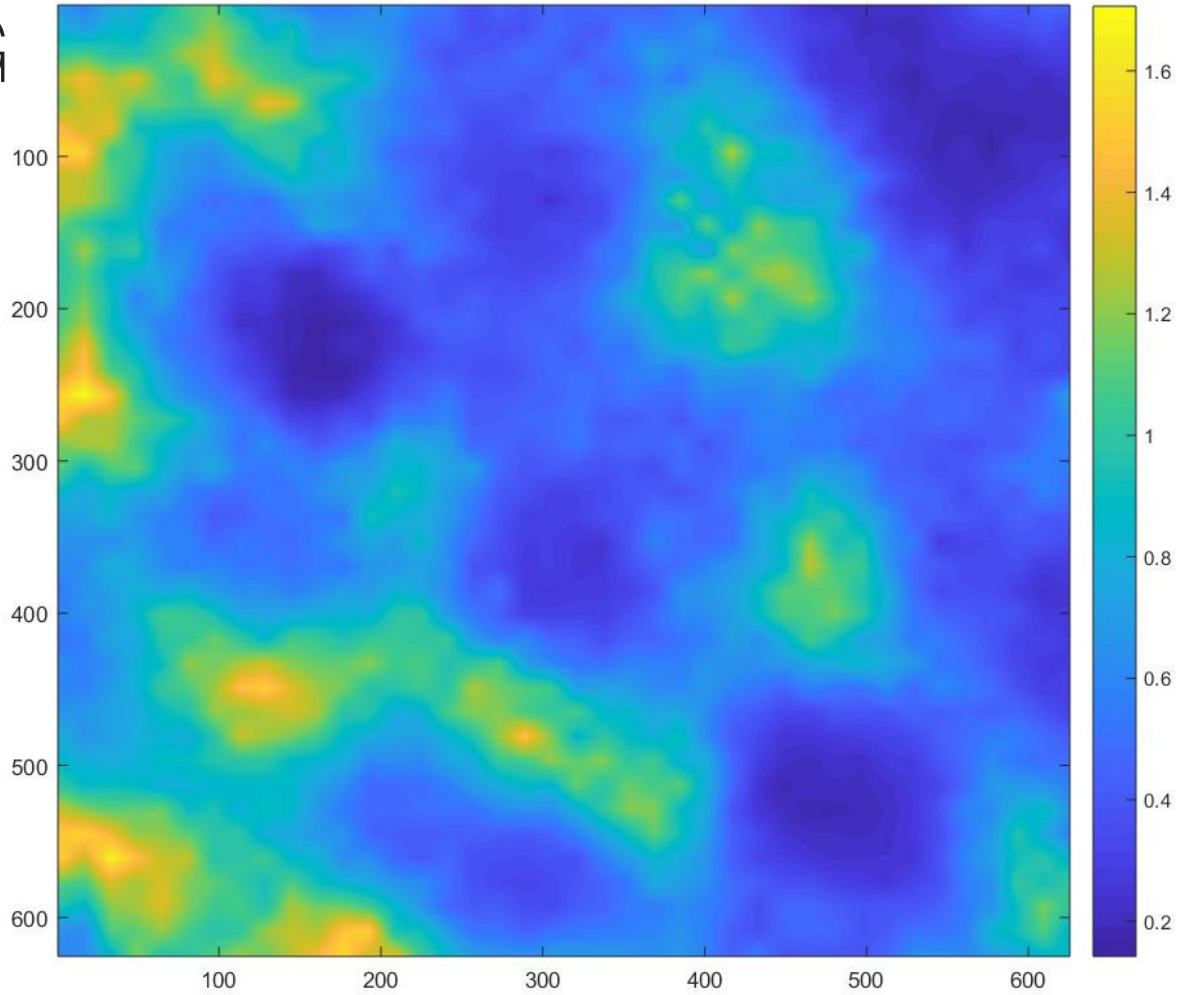
Raman spectroscopy - graphene



[4]

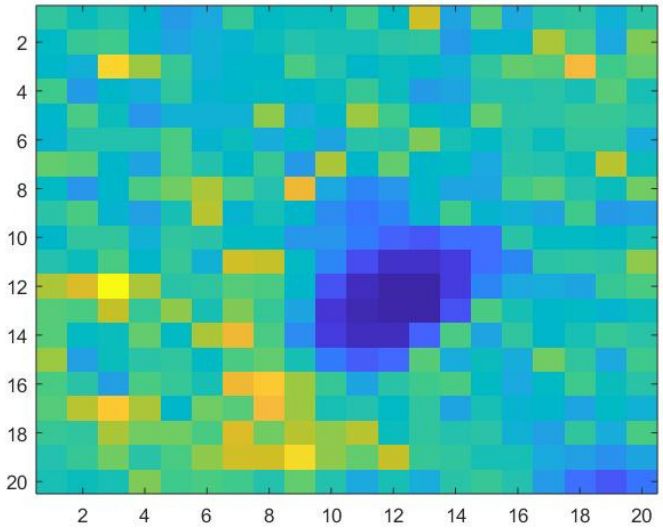
Raman spectroscopy - graphene

I2D/IG

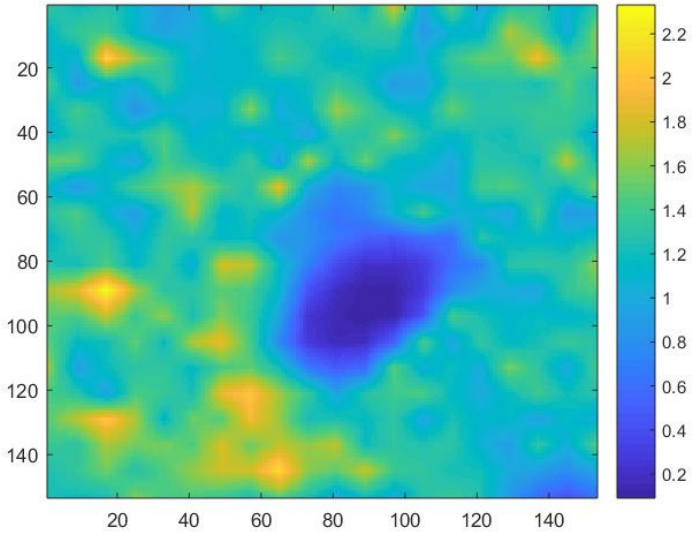


for single layer
I2D/IG~2

Gradient simulation - graphene

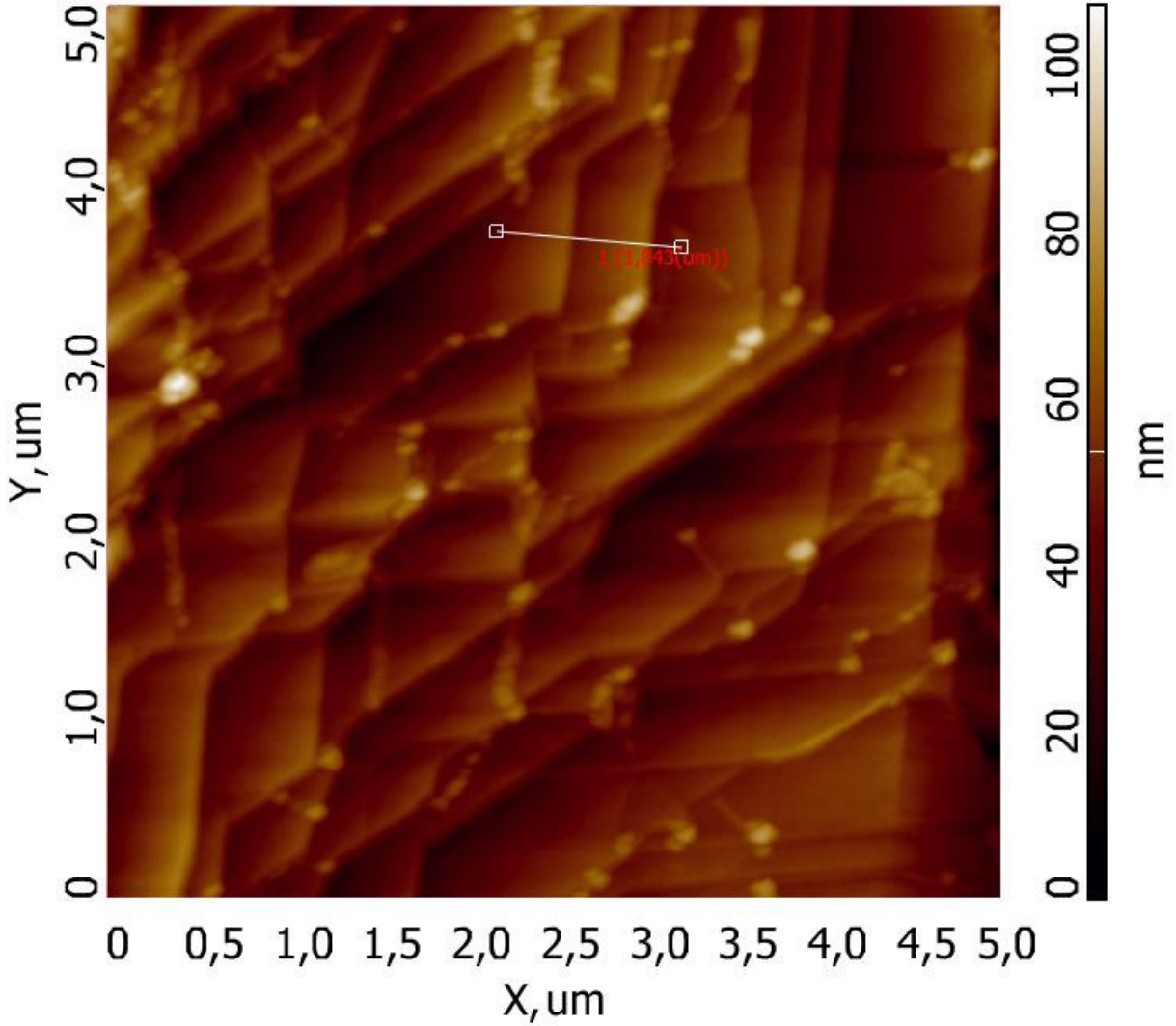


10s single measurement - 40x40 takes ~4,5h



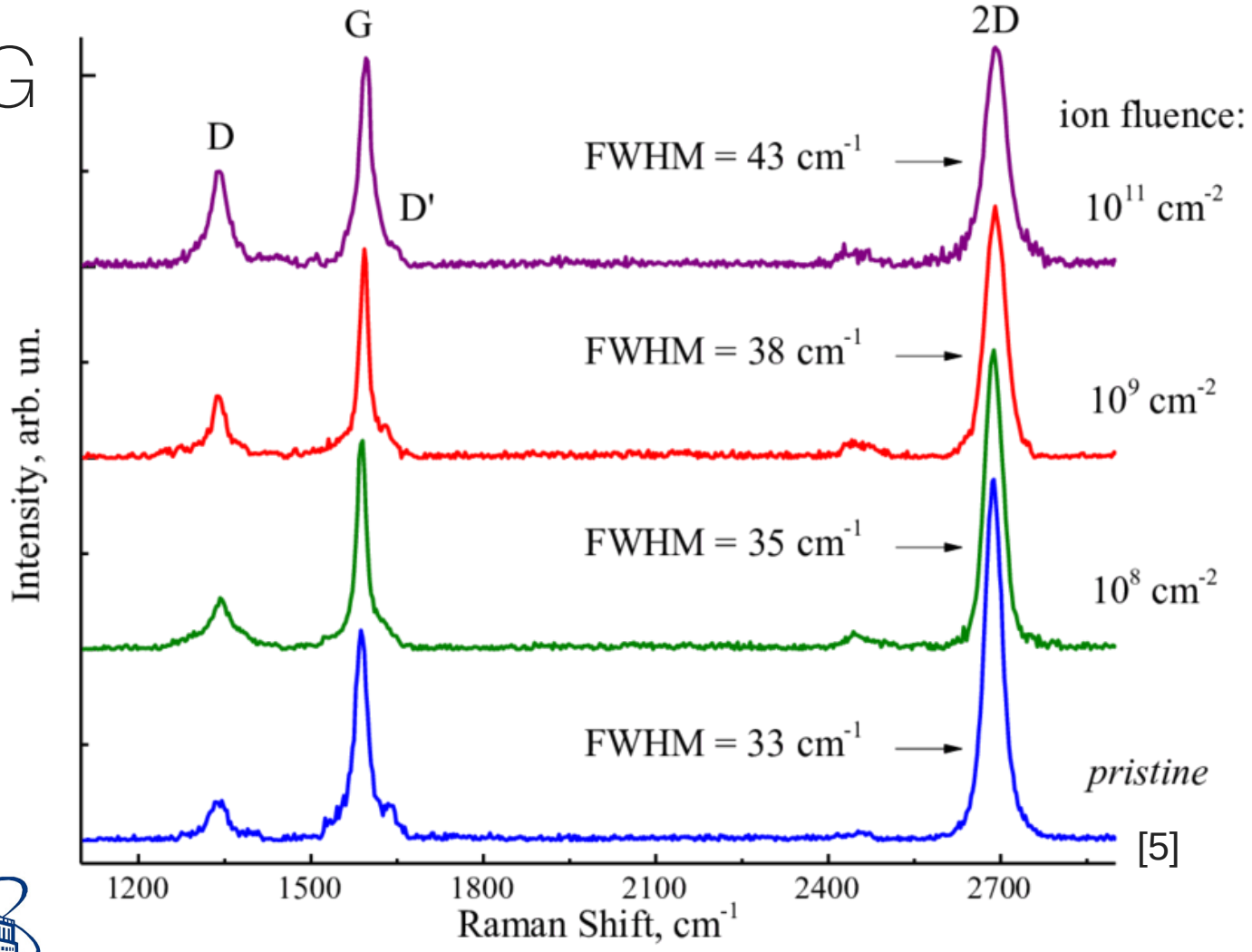
10s single measurement - 153x153 takes over 65h!

Raman spectroscopy - graphene



Raman spectroscopy - graphene

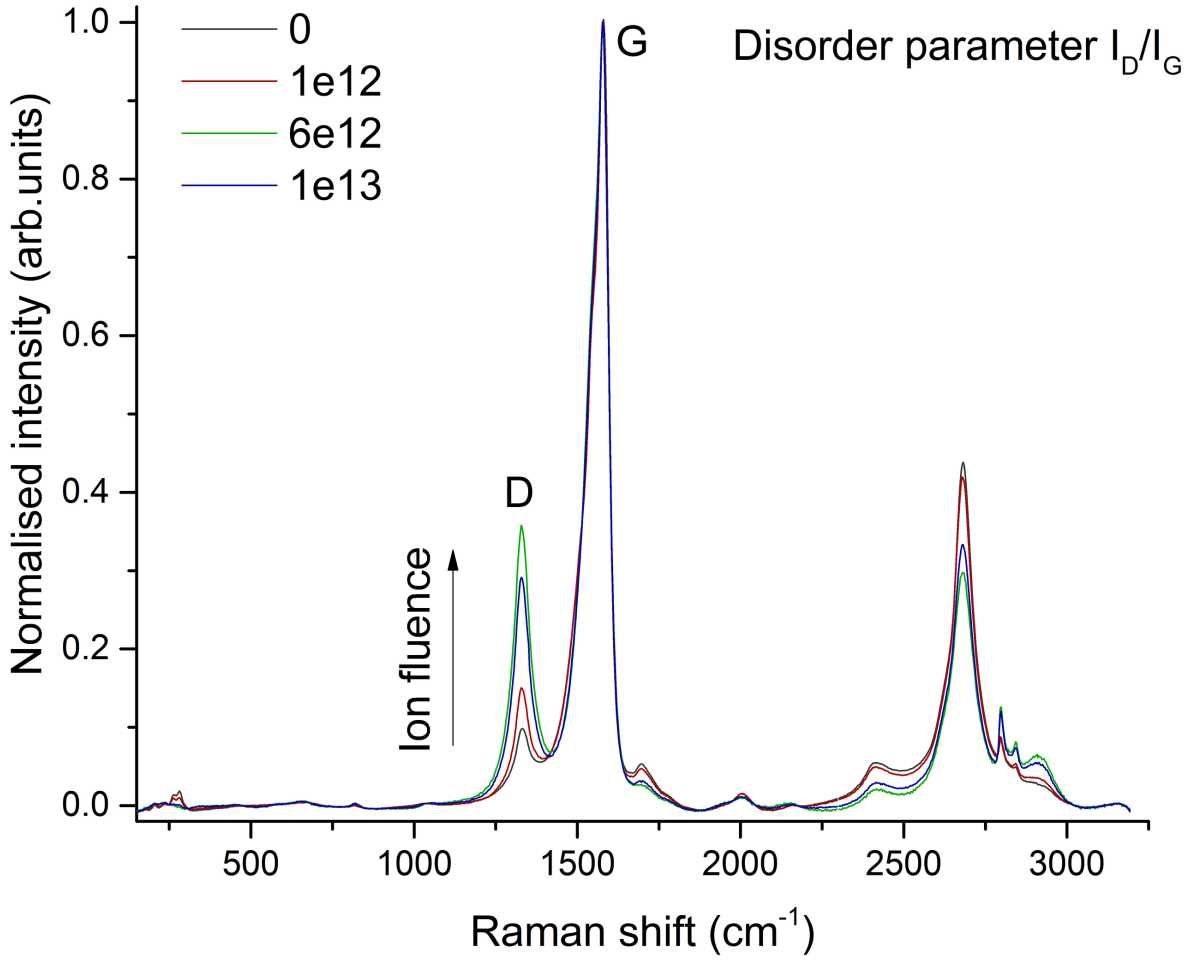
ID/IG



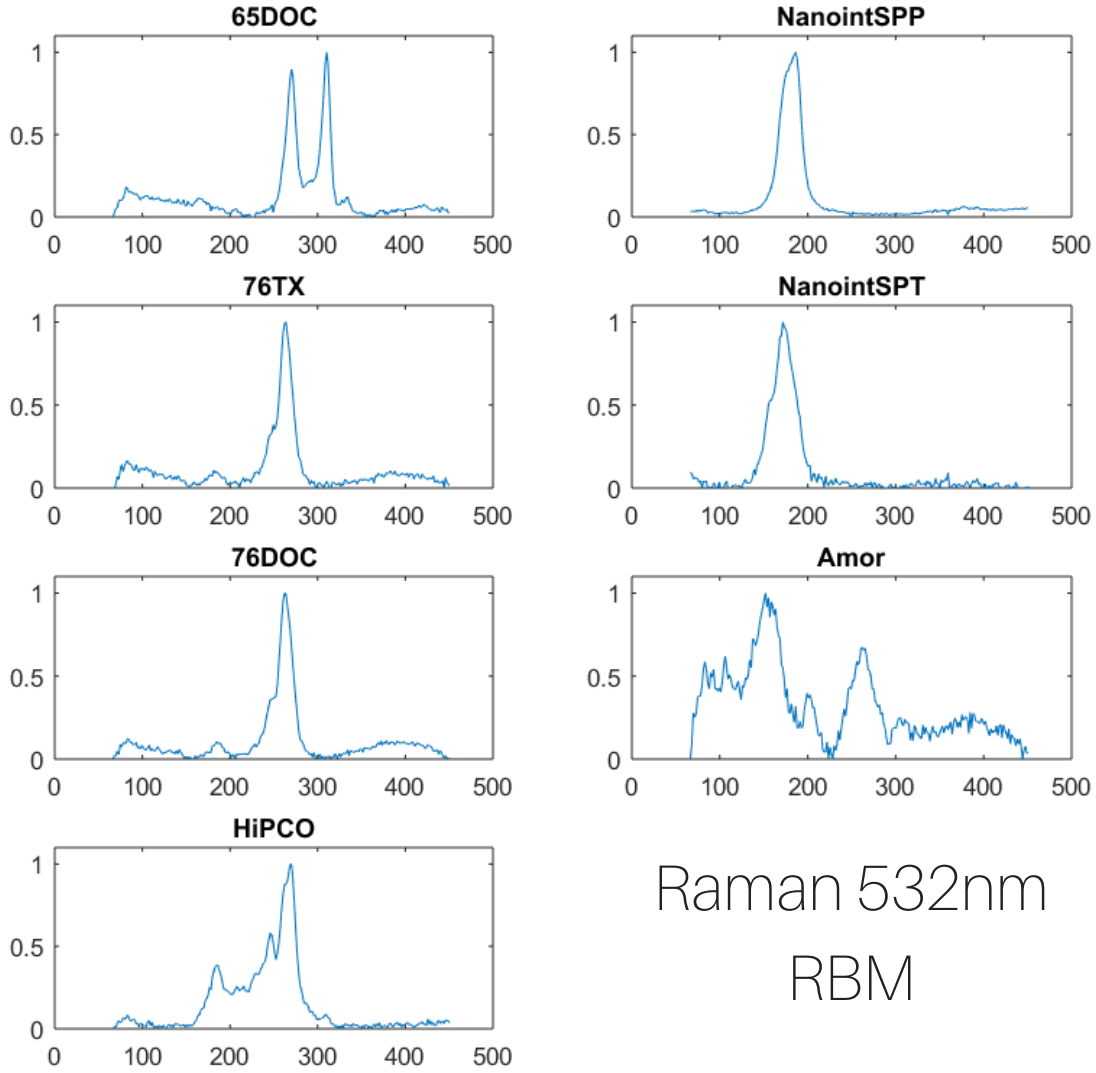
[5]

Raman spectroscopy - SWNTs

Raman 473nm



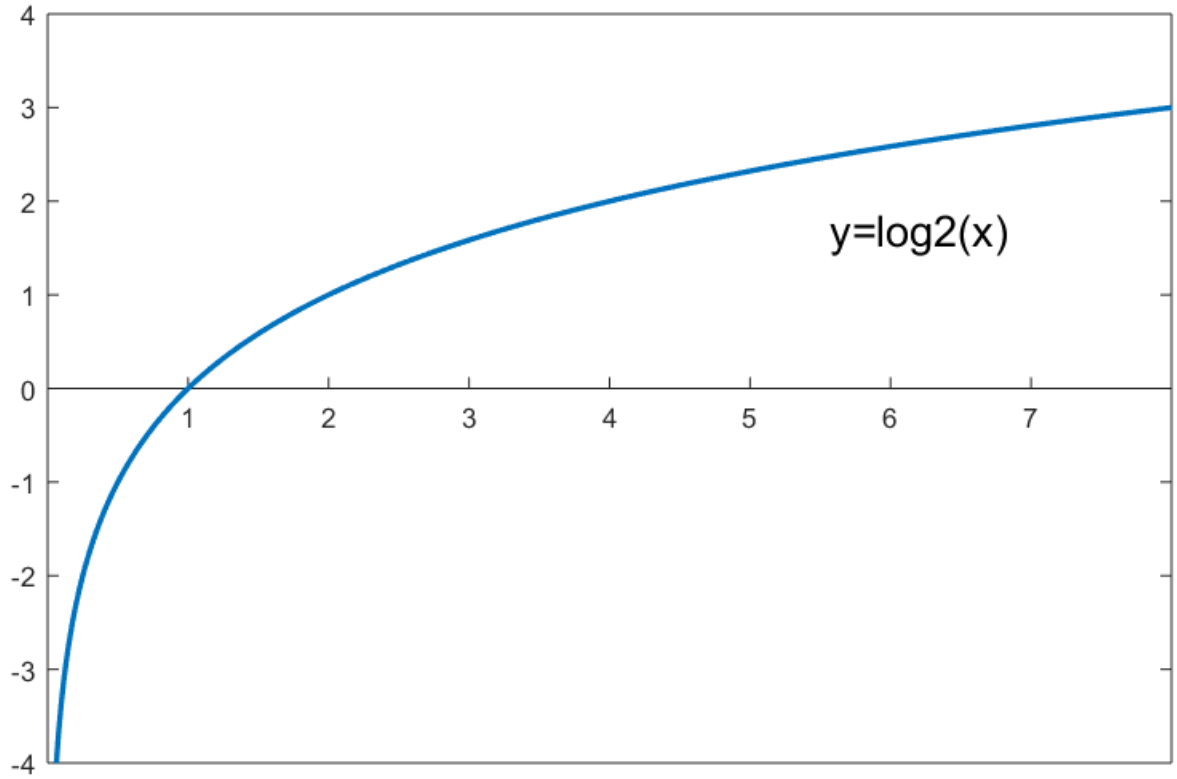
Raman spectroscopy - SWNTs



Raman 532nm

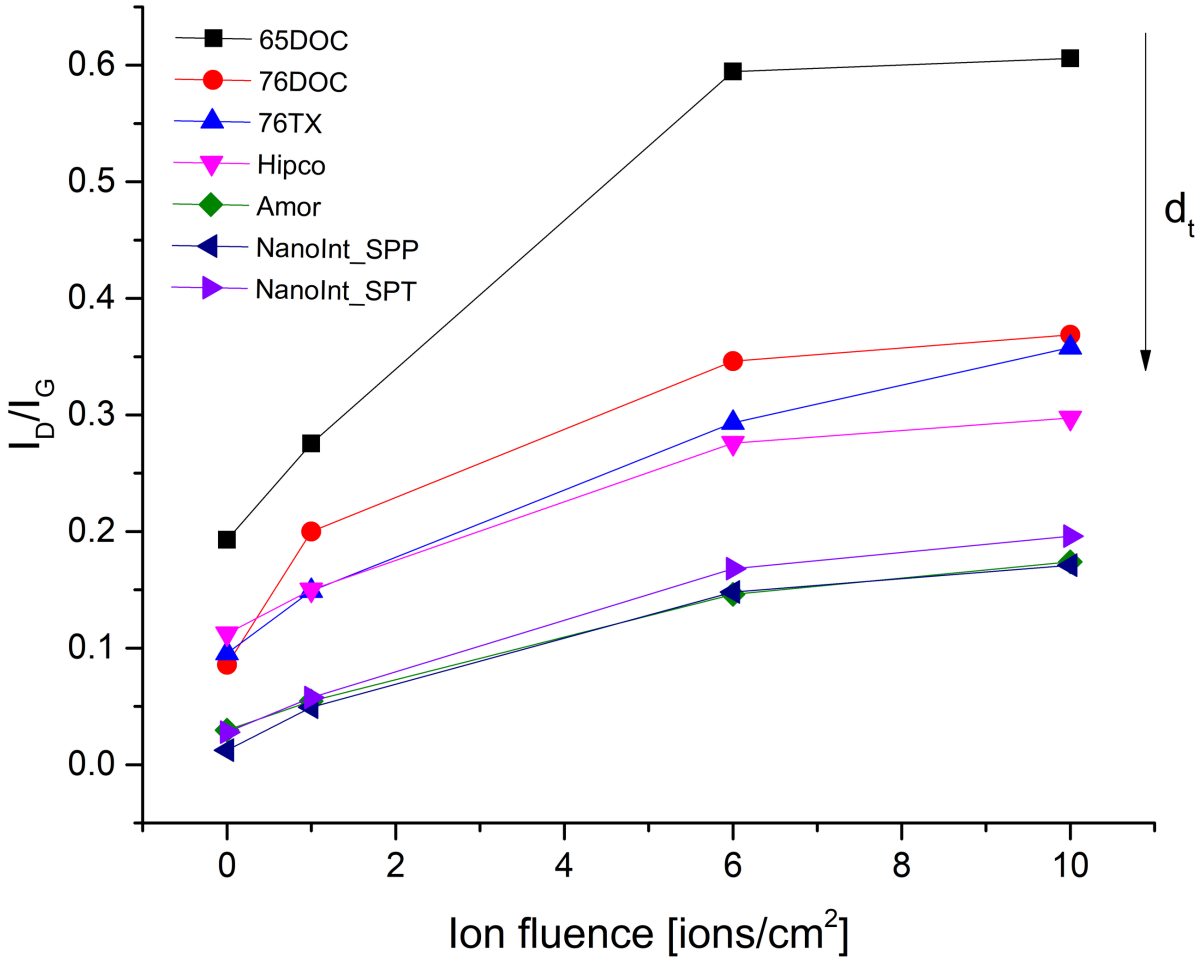
RBM

Raman spectroscopy - SWNTs

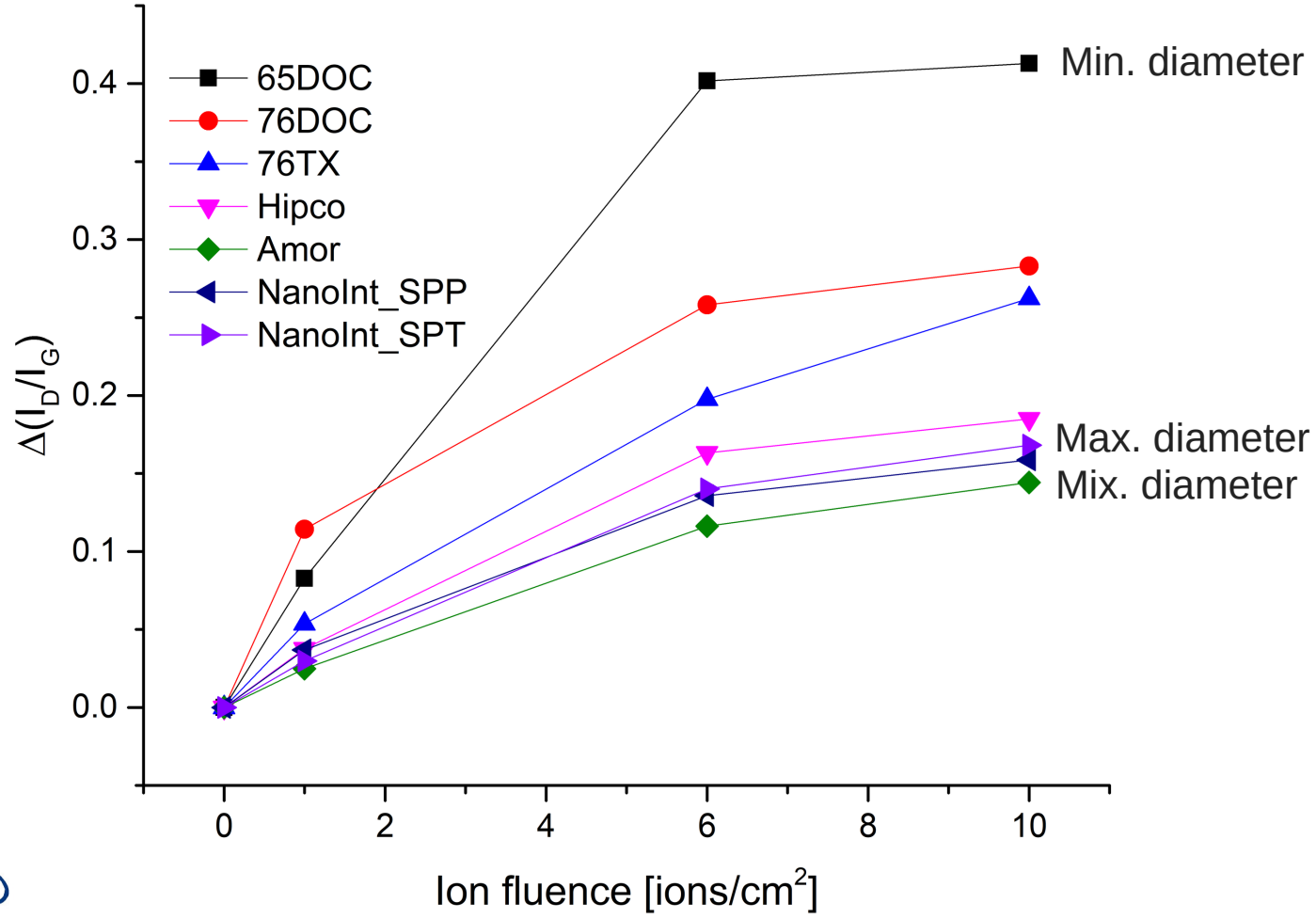


Raman spectroscopy - SWNTs

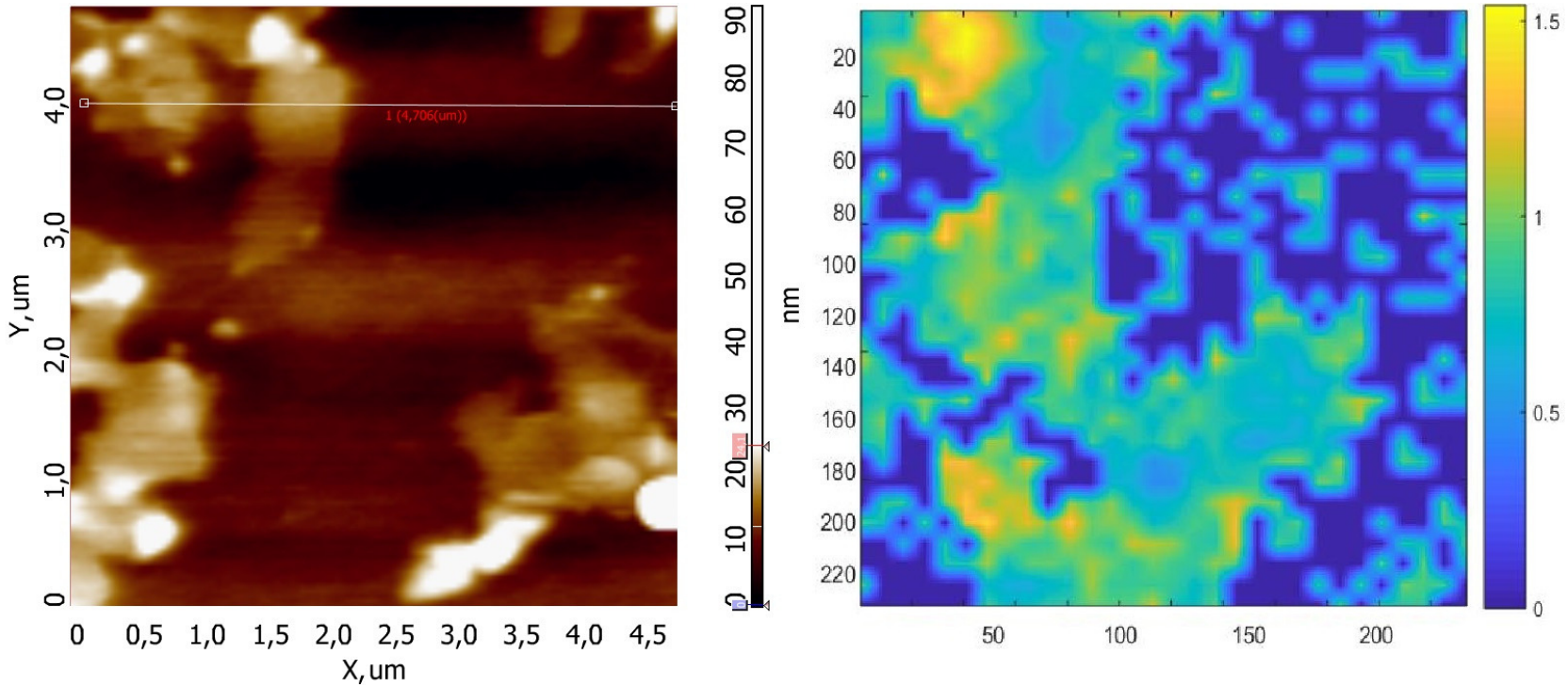
lines for increased readability!



Raman spectroscopy - SWNTs



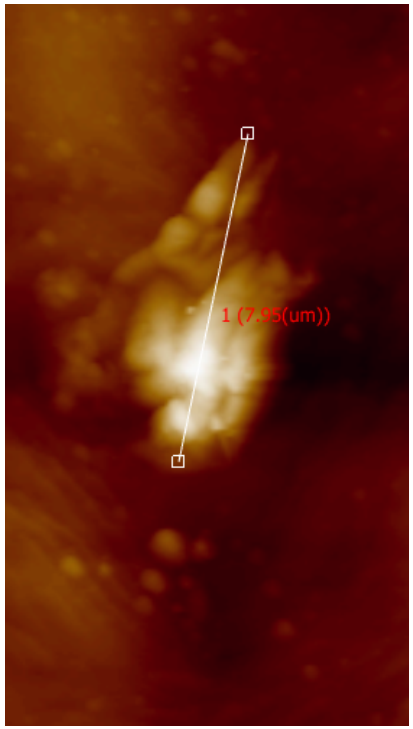
Mixed method



Defect characterisation - summary

- Laser spot size in spectroscopy
- Size of defects - overlapping, visibility
- Quality ≠ quantity
- Initial quality of the sample

Solution? Complex approach!



Acknowledgements

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- IC-100 cyclotron team
- Kacper Drużbicki, PhD (UAM, FLNP JINR)

References

1] http://flerovlab.jinr.ru/flnr/ic-100.html (access 17.04.2018)
[2] A. V. Krasheninnikov, K. Nordlund, J. Keinonen, and F. Banhart. Ion-irradiation-induced welding of carbon nanotubes. Phys. Rev. B, 66(24):245403, December 2002.
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