

HIGH-ENERGY ION IRRADIATION OF CARBON NANOSTRUCTURES AND DEGREE OF DAMAGE



CHARACTERISATION



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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/cm² and reference sample (non irradiated)



[1]



CARBON NANOSTRUCTURES

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



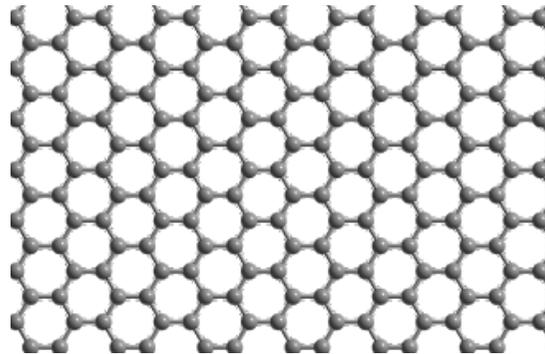
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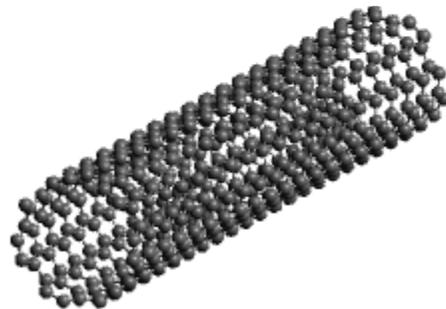


CARBON NANOSTRUCTURES

GRAPHENE

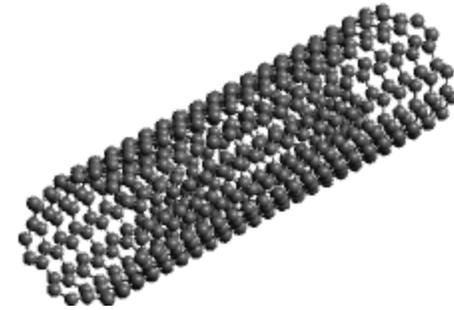
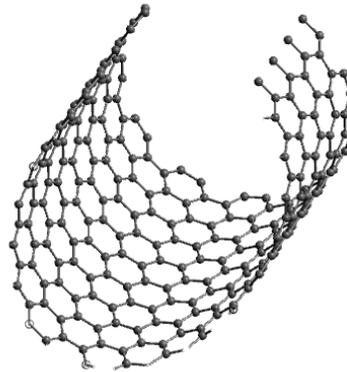
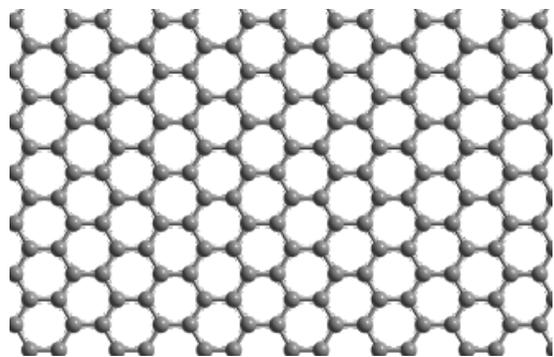


SINGLE-WALLED CARBON NANOTUBES (SWNT)



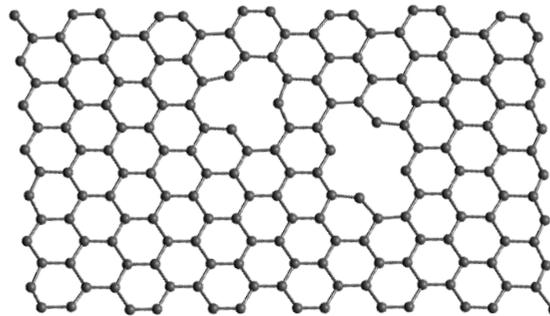
CARBON NANOSTRUCTURES

GRAPHENE  SWCNT

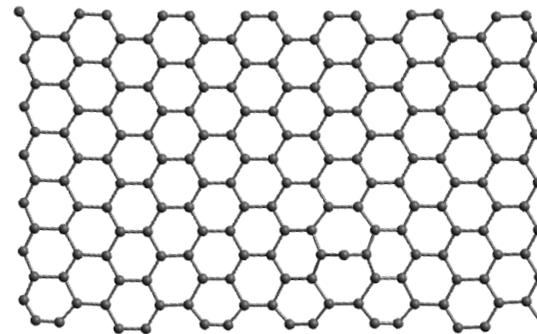
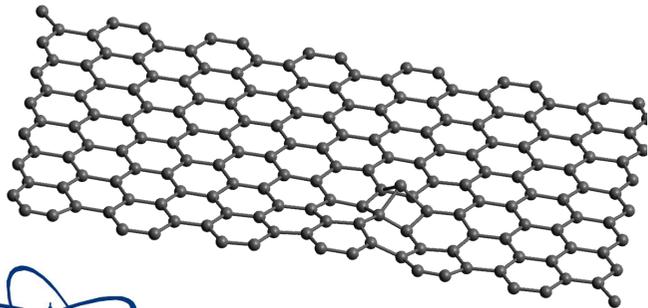


DEGREE OF DAMAGE - DEFECTS

Vacancies: single, double etc.

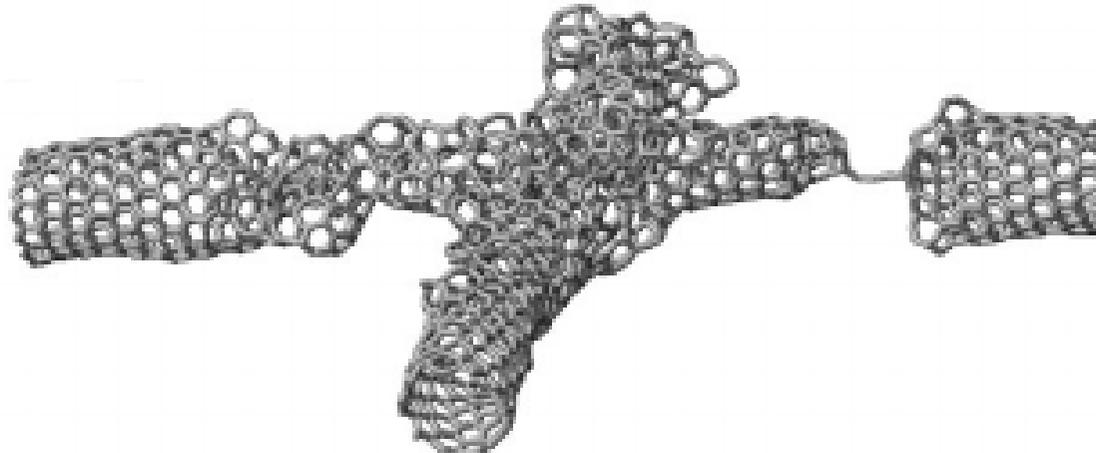


Ad-atoms, interstitials



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)



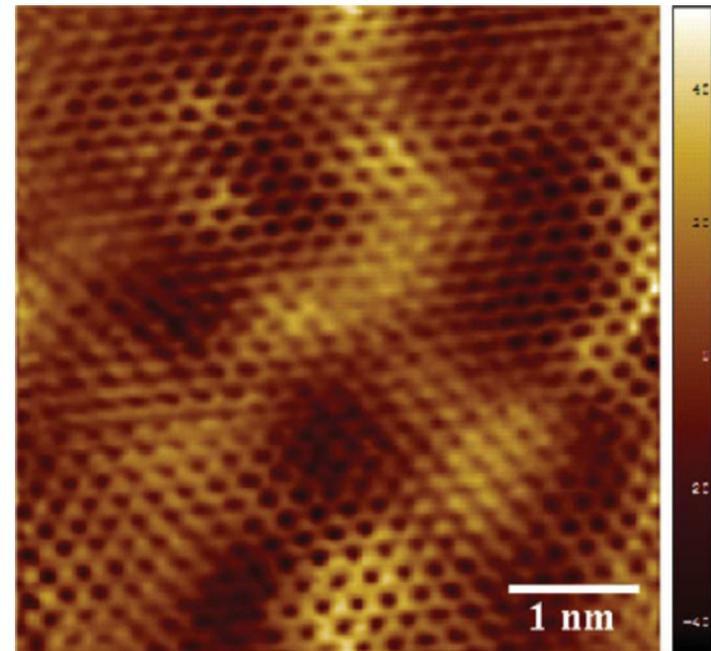
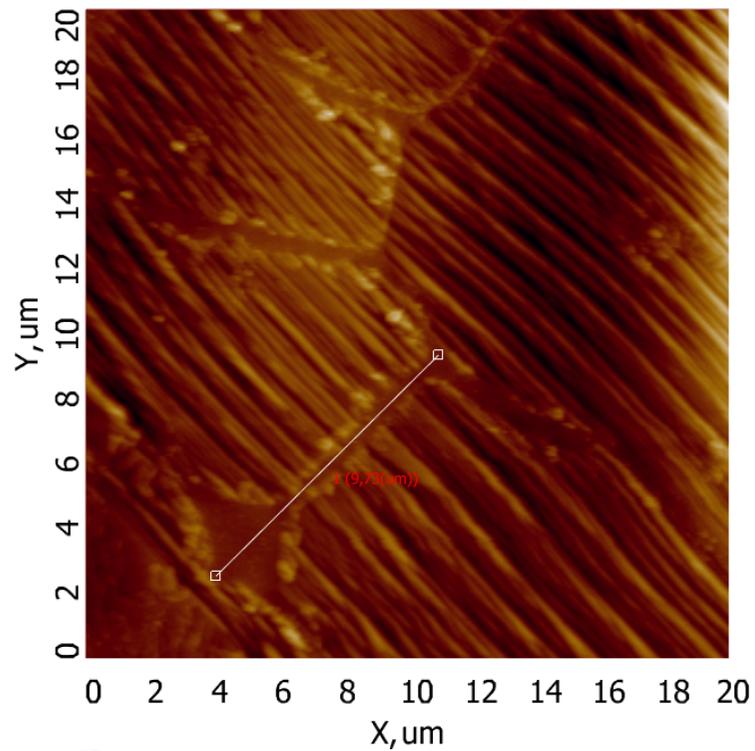
DAMAGE MEASUREMENTS

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MICROSCOPY

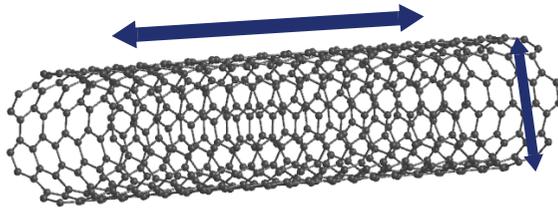
AFM, STM



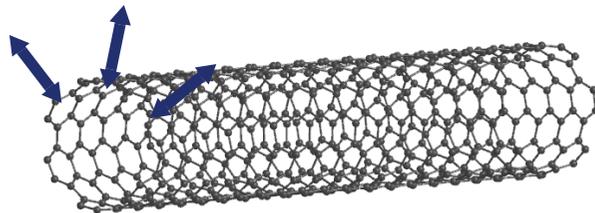
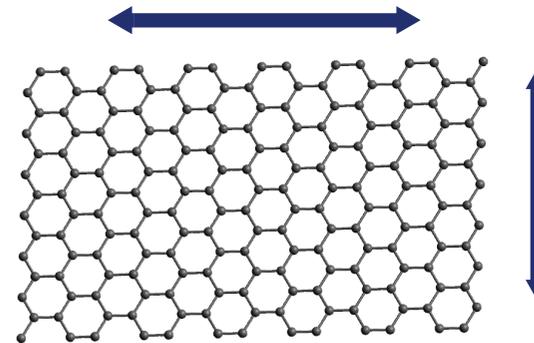
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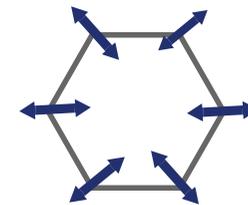
RAMAN SPECTROSCOPY



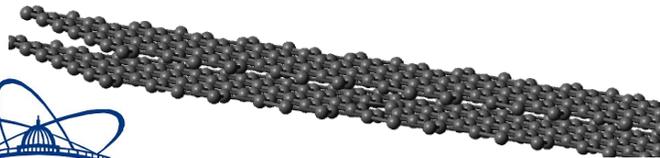
G band



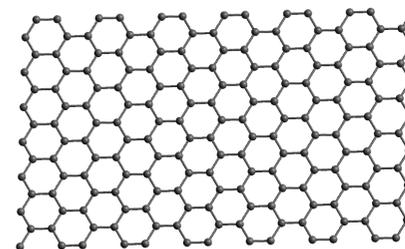
RBM band



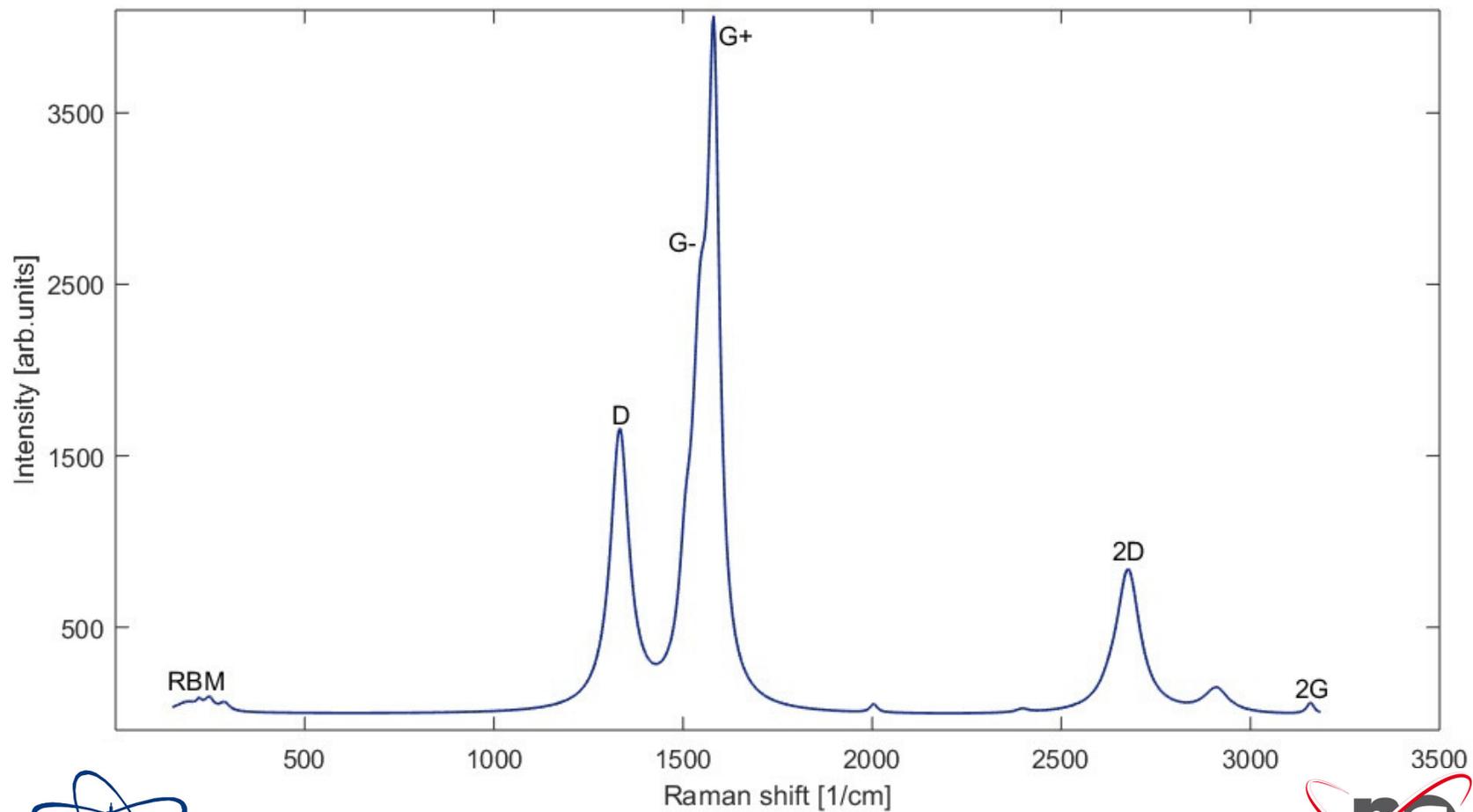
D band - ring breathing mode
with defects



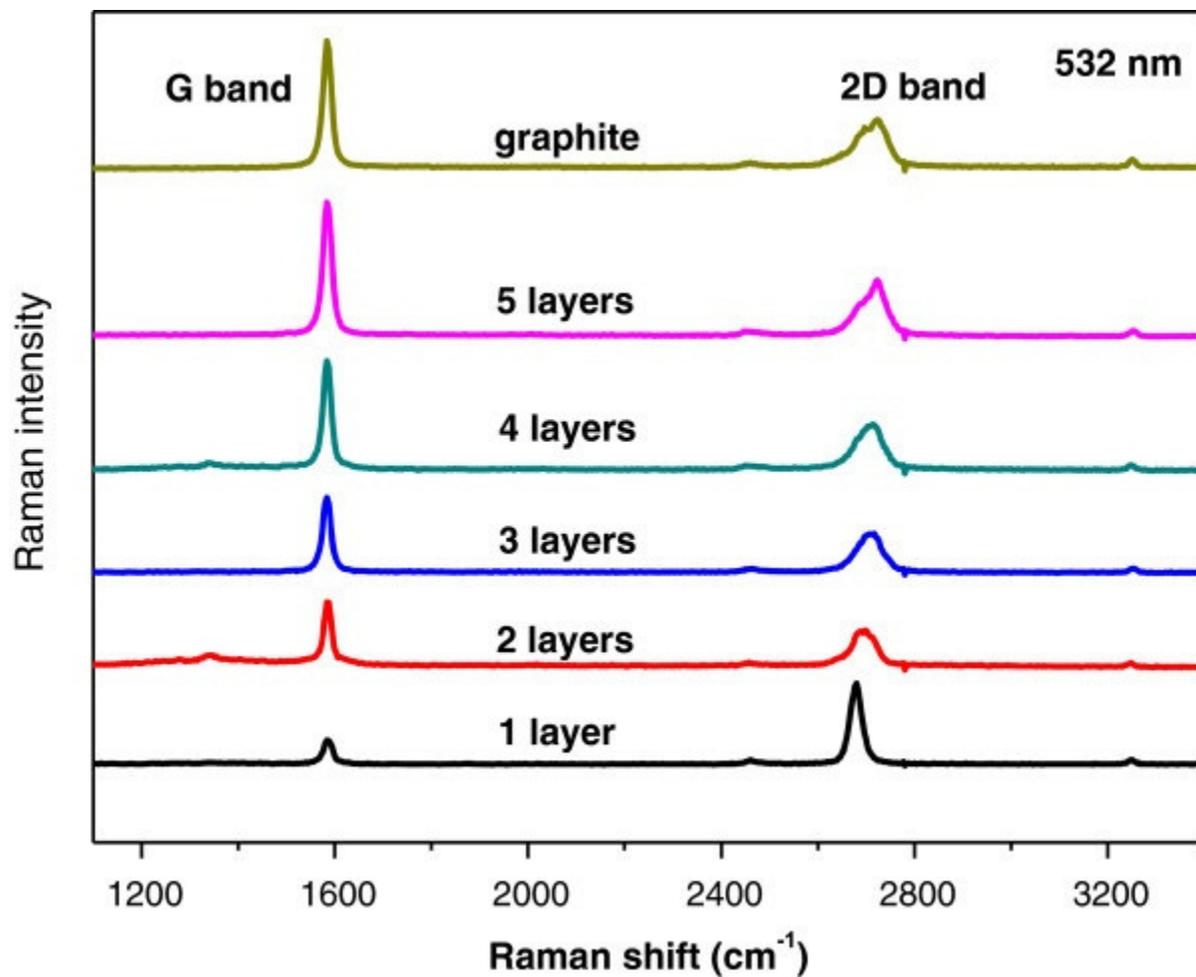
2D band



RAMAN SPECTROSCOPY



RAMAN SPECTROSCOPY - GRAPHENE

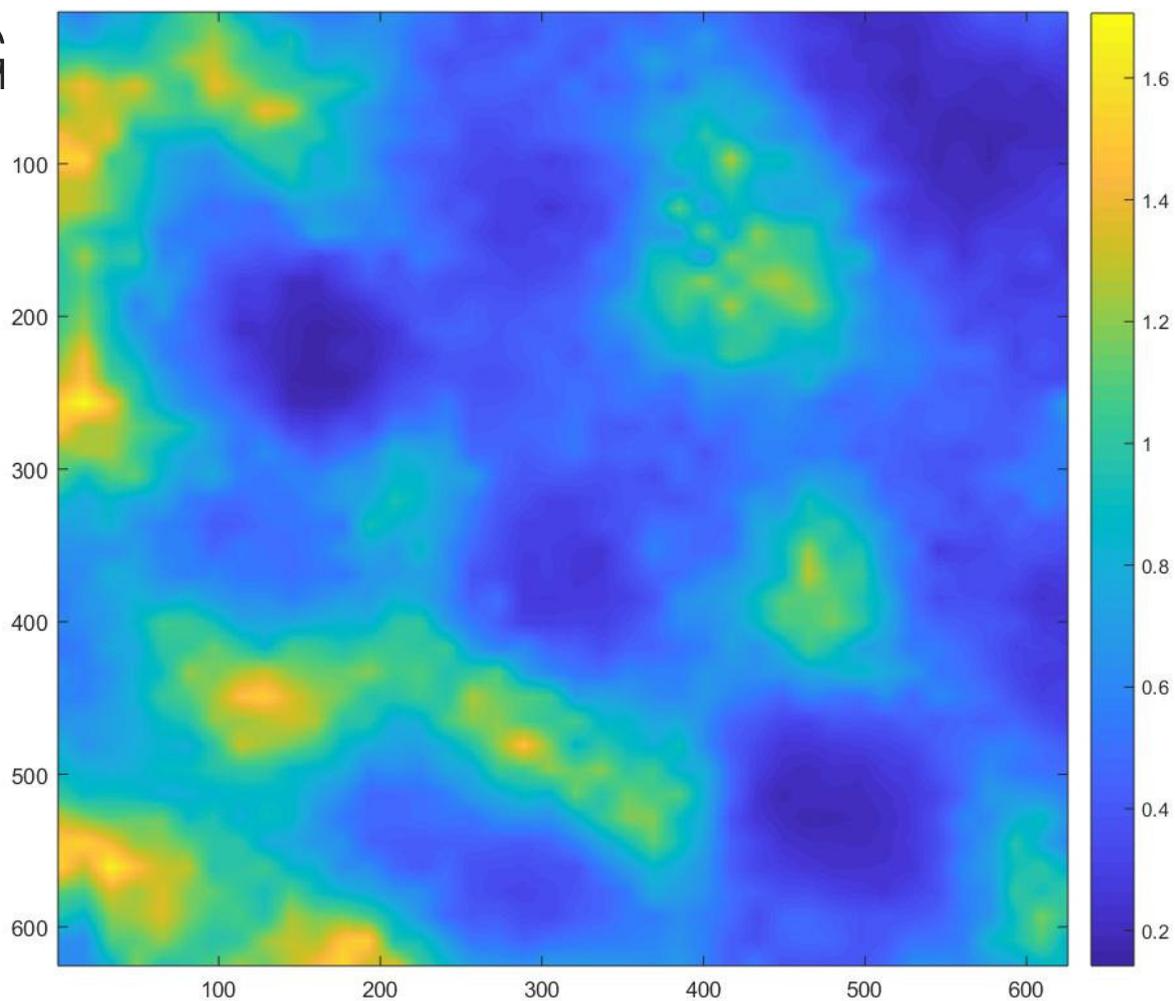


[4]



RAMAN SPECTROSCOPY - GRAPHENE

I2D/IG

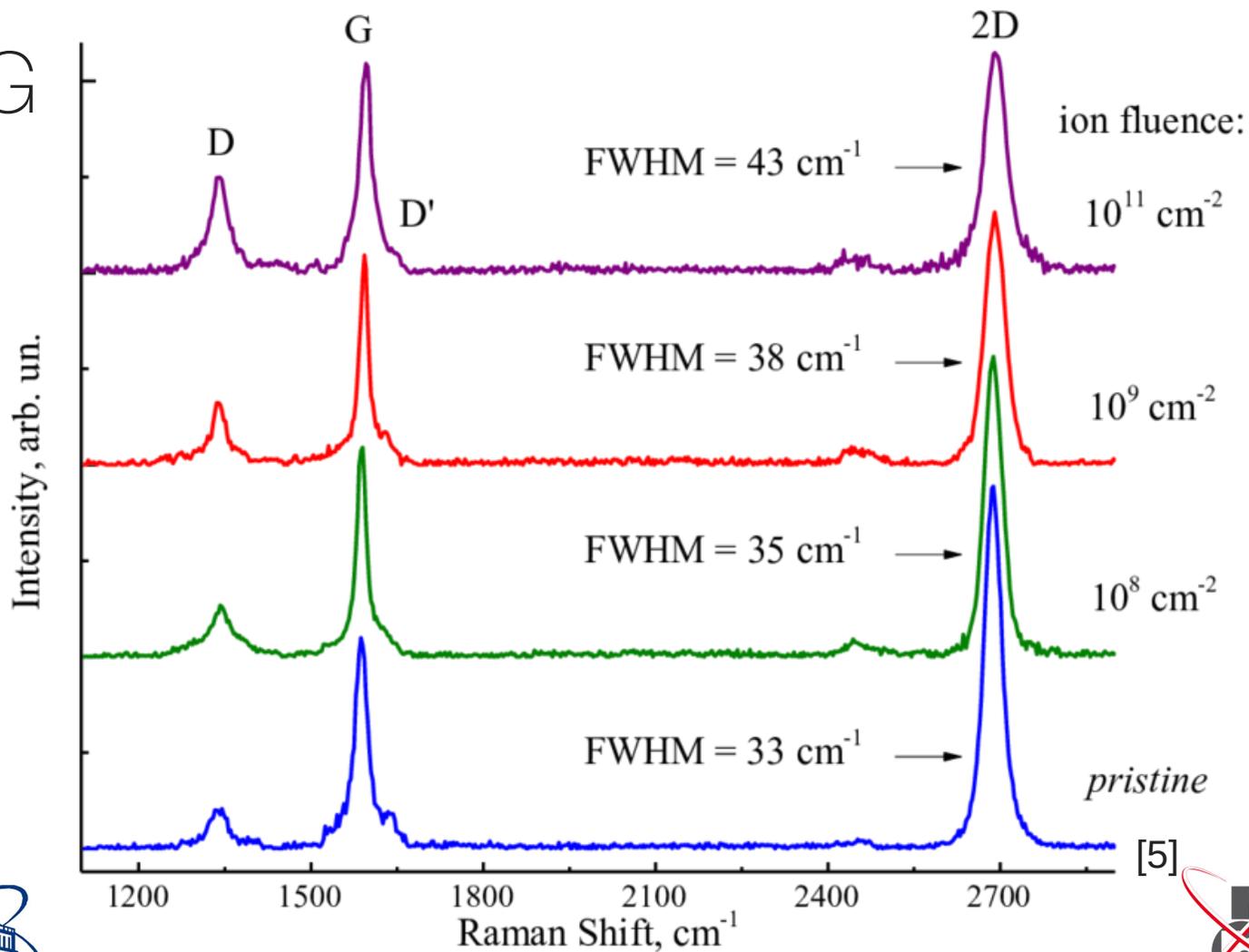


for single layer
I2D/IG~2



RAMAN SPECTROSCOPY - GRAPHENE

ID/IG

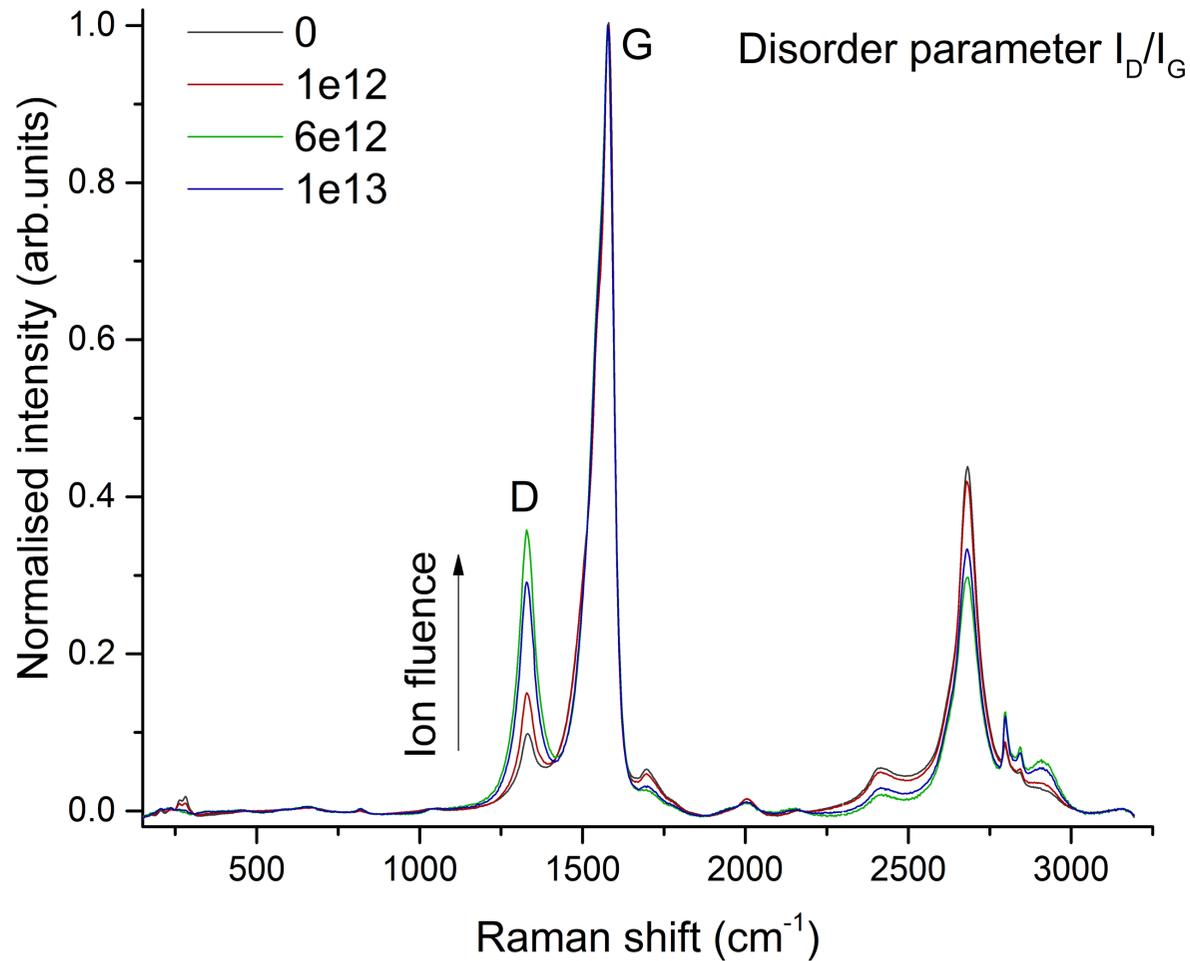


[5]

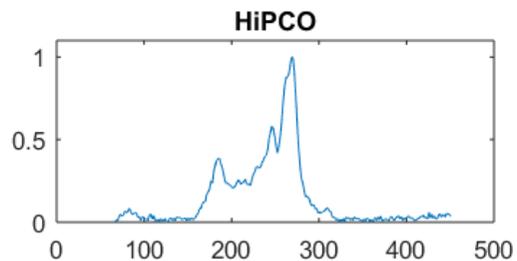
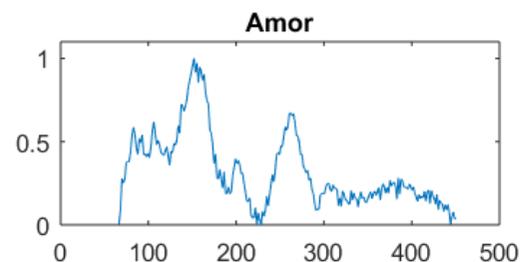
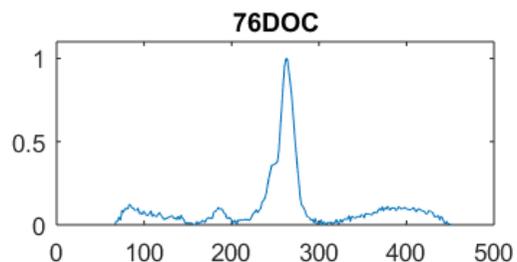
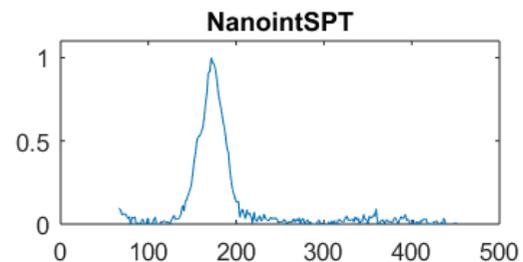
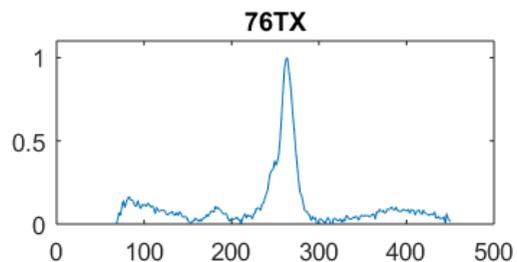
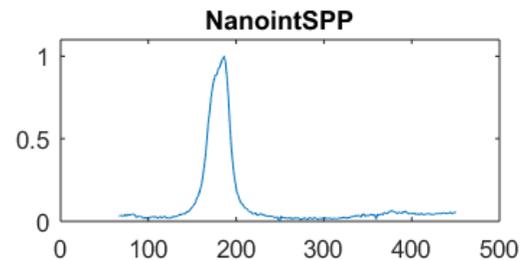
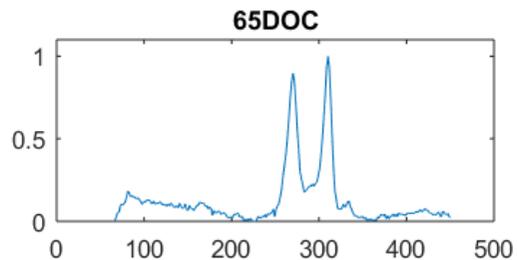


RAMAN SPECTROSCOPY - SWNTs

Raman 473nm



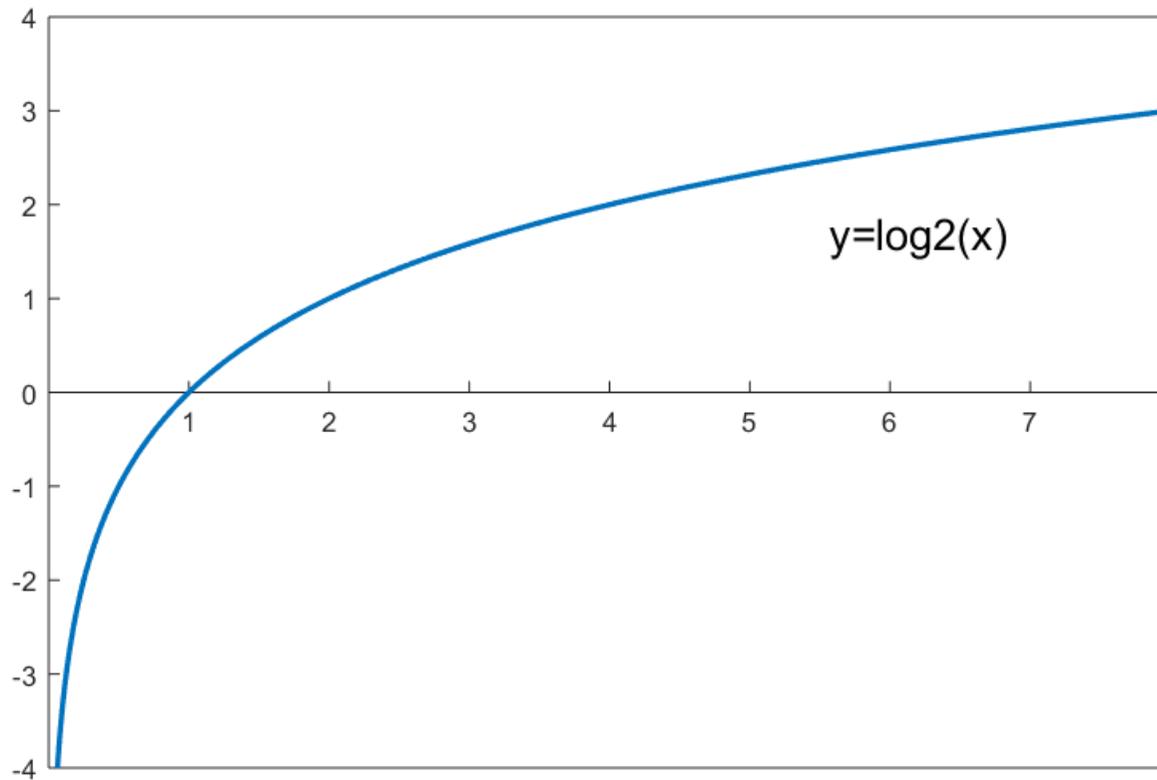
RAMAN SPECTROSCOPY - SWNTs



Raman 532nm
RBM

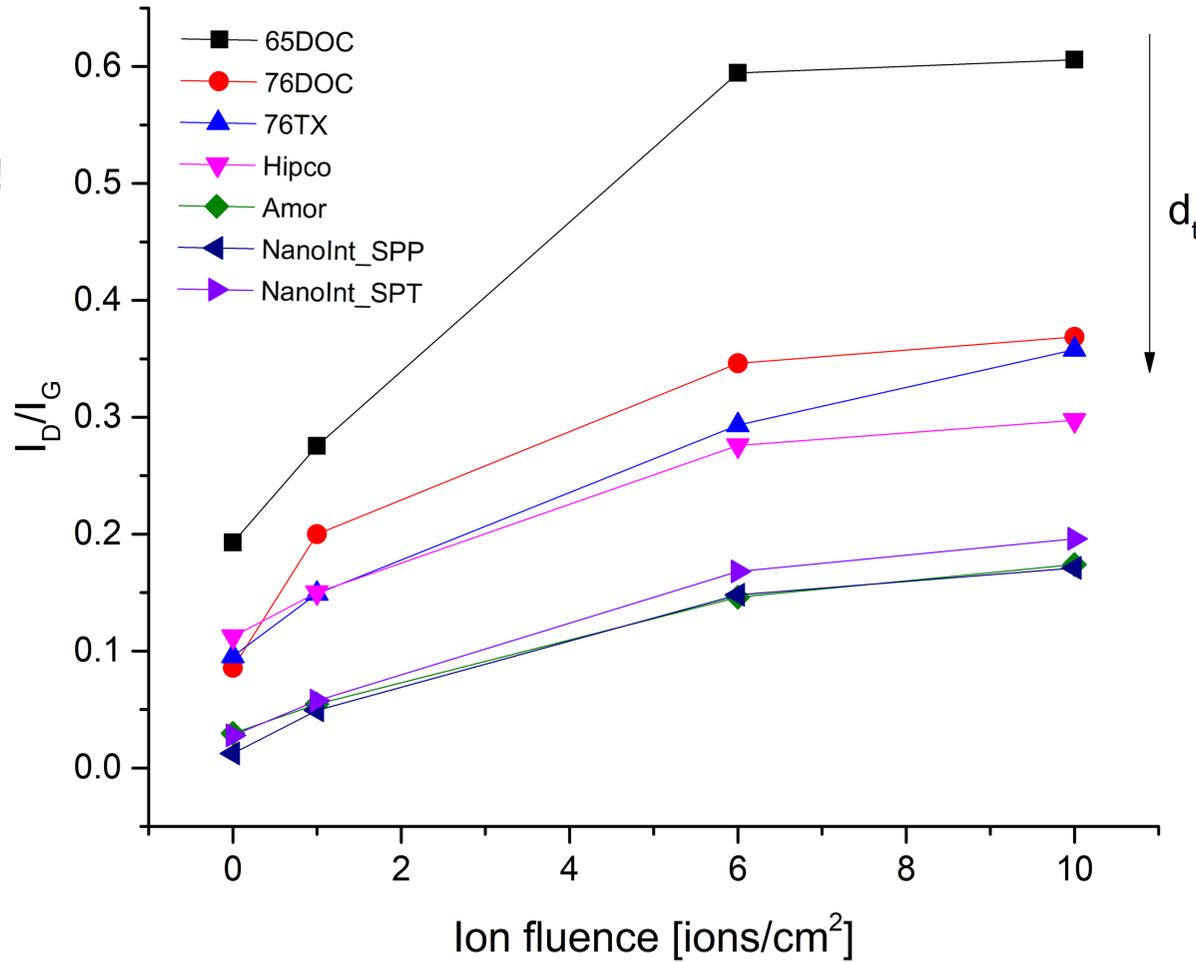


RAMAN SPECTROSCOPY - SWNTs

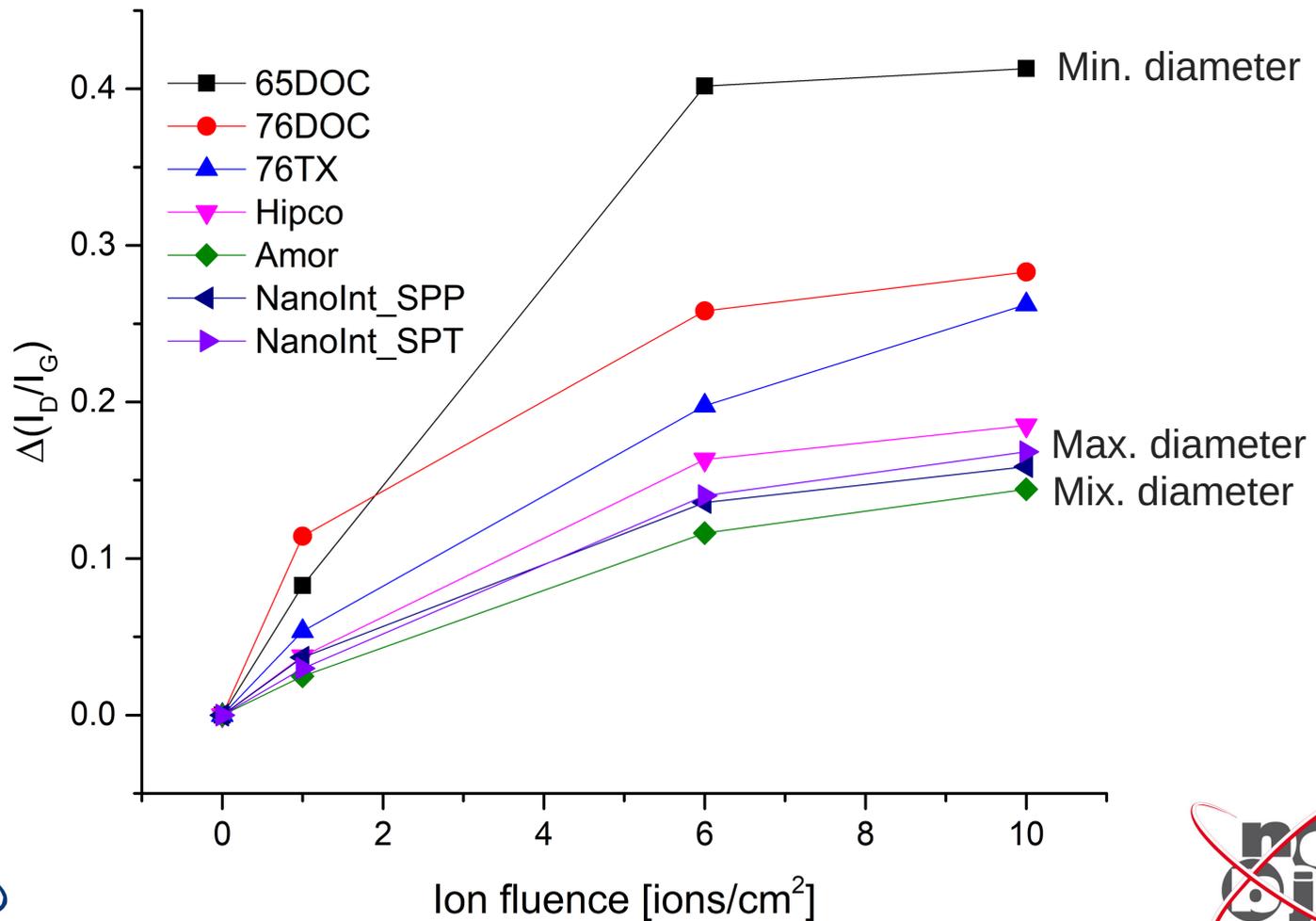


RAMAN SPECTROSCOPY - SWNTs

lines for
increased
readability!



RAMAN SPECTROSCOPY - SWNTs

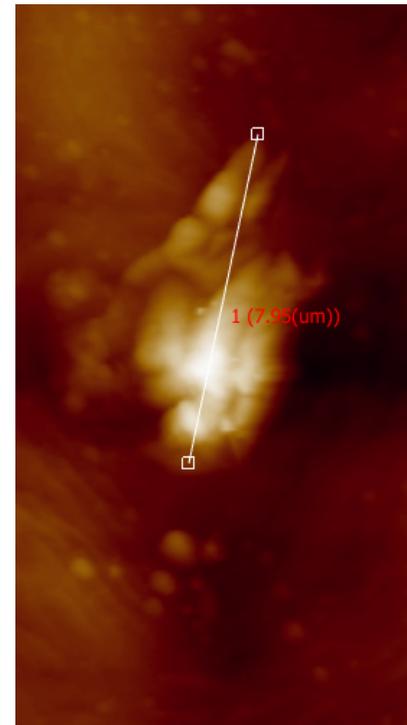


DEFECT CHARACTERISATION

- SUMMARY

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

Solution? Complex approach!



ACKNOWLEDGEMENTS

- Andrzej Olejniczak (UMK, FLNR JINR)
- IC-100 cyclotron team
- Kacper Drużbicki, PhD (UAM, FLNP JINR)



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THANK YOU
FOR
ATTENTION!

