

Engineering and characterization of large area, aligned single-wall carbon nanotubes

Luis Alejandro Royo Romero

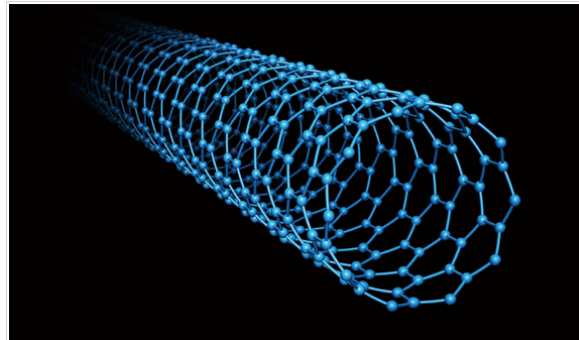
NIST Advisor: Dr. Angela Hight Walker

August 4th, 2017

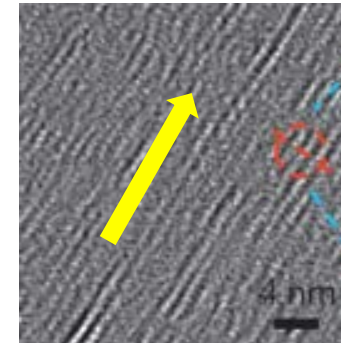
NIST
**National Institute of
Standards and Technology**
U.S. Department of Commerce

Main Goal

- Establish a NIST capability to produce large area, highly aligned Single-Wall Carbon Nanotubes (SWCNT) films for nanoelectronics devices
- Optimize SWCNTs film alignment protocol¹ utilizing NIST's SWCNTs



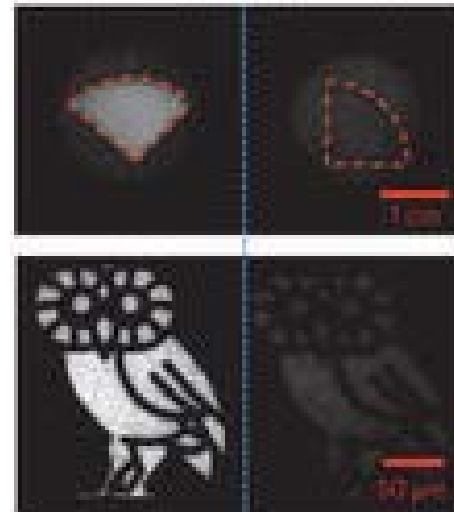
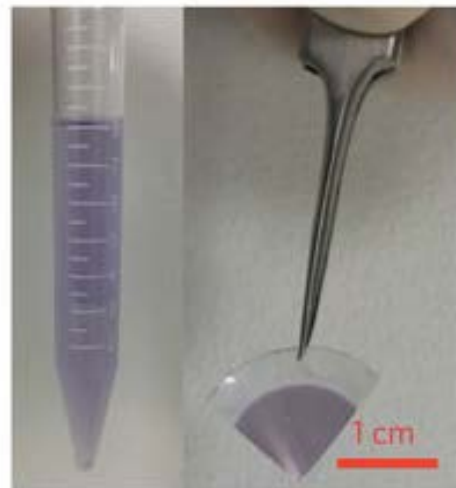
<http://www.tasc-nt.or.jp/en/project/characteristic.html>



He, X. ,et al, *Nature Nanotechnology* 633 (2016)

Motivation

- SWCNTs possess unique optical and electronic properties that are enhanced at the macroscopic scale in well-aligned films



He, X., et al, Nature Nanotechnology Figure 1,3

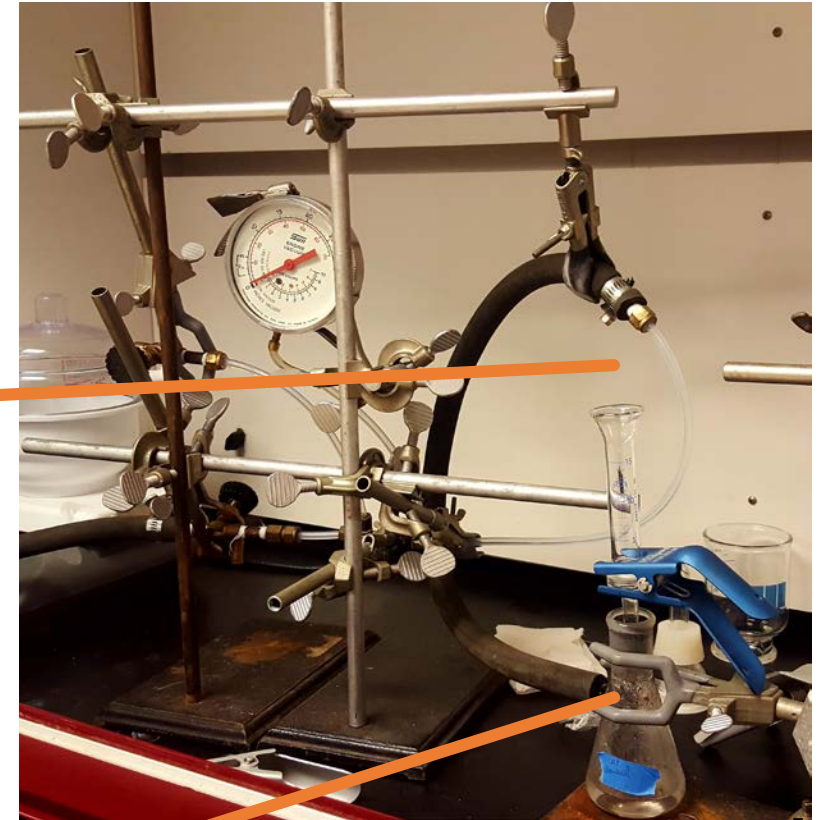
Experimental Set Up: Producing Aligned Films

SWCNT
Suspension

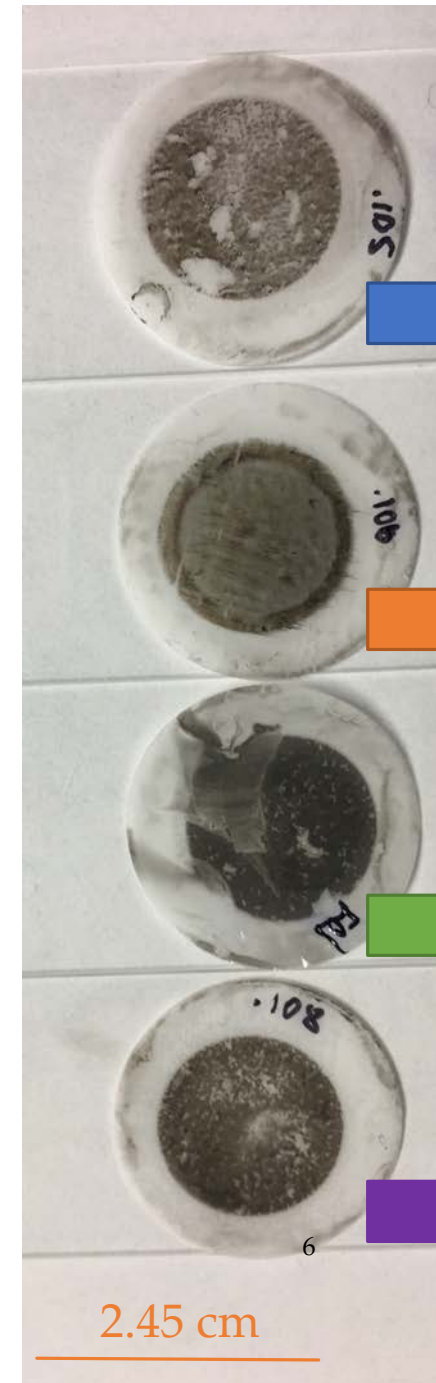
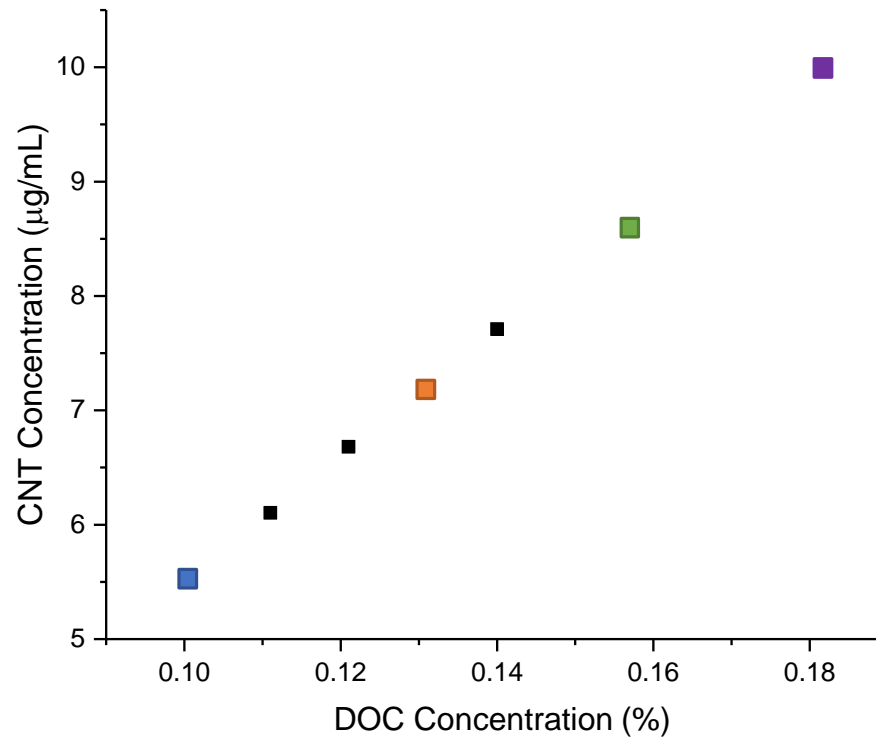
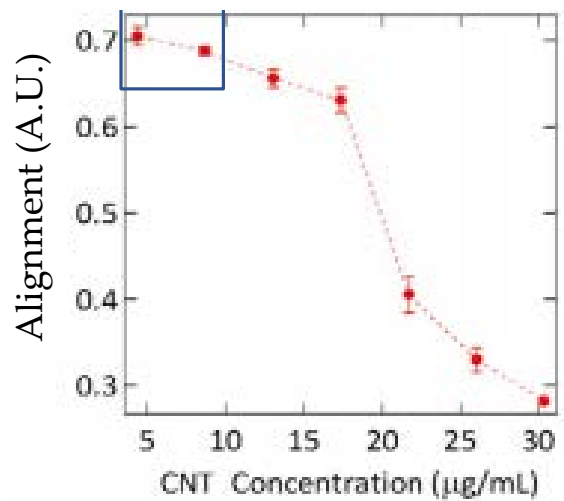
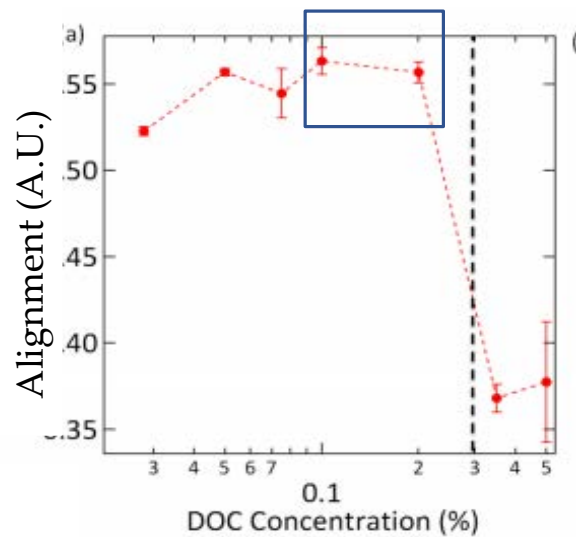


From Jeff Fagan

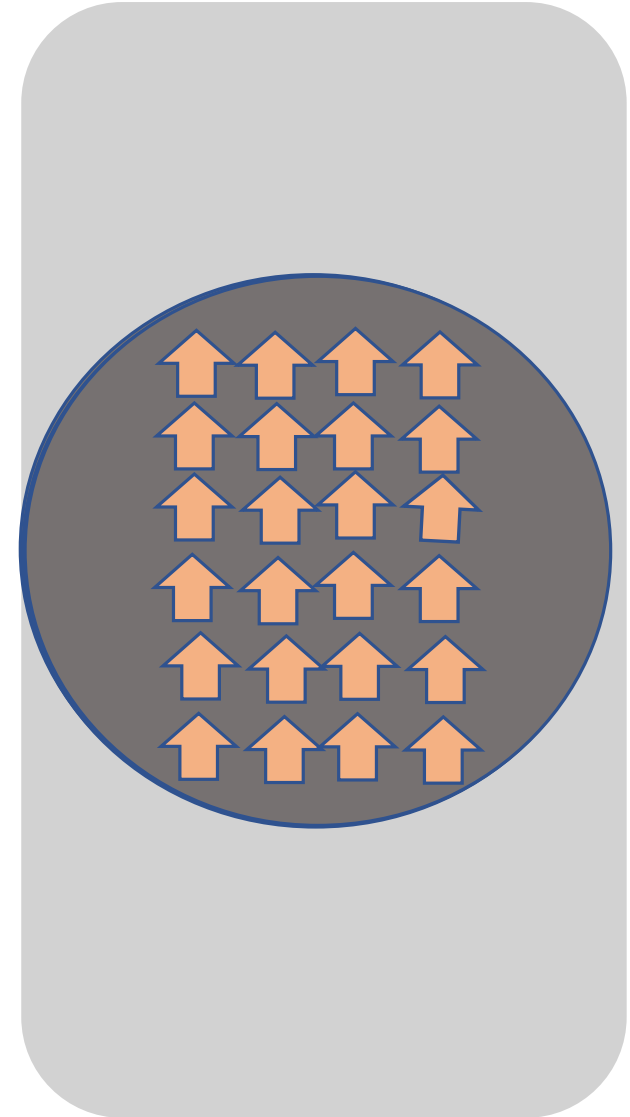
Vacuum Filtration Apparatus



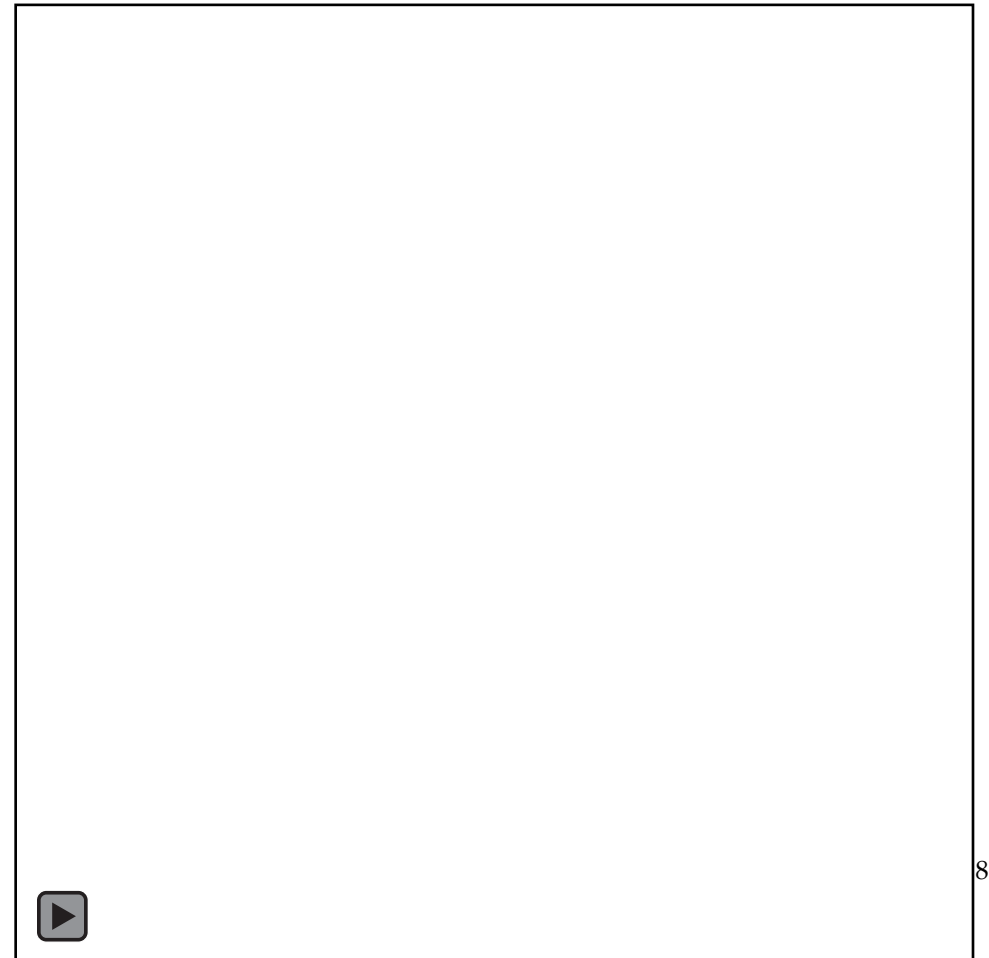
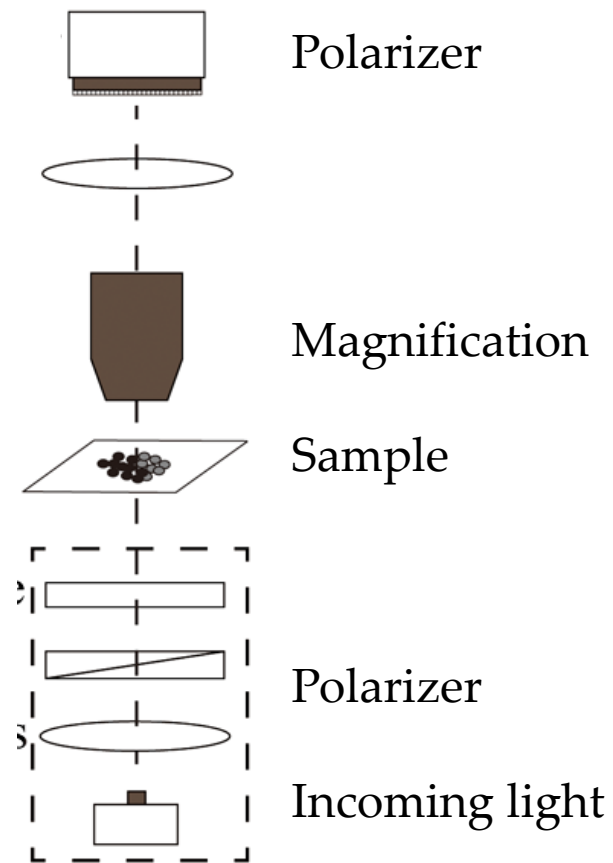
Film Alignment Optimization



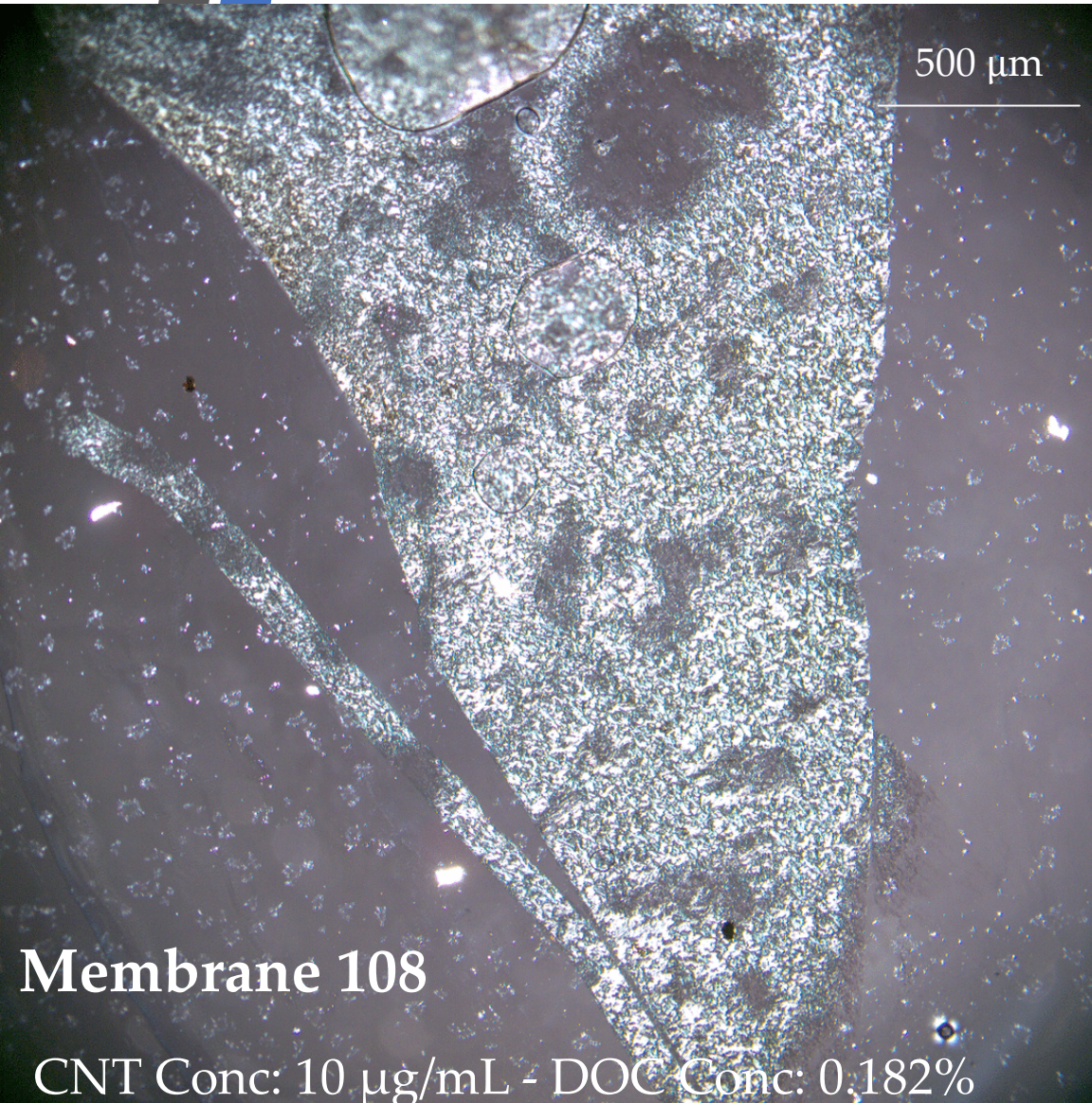
Transfer Process & Domain Size



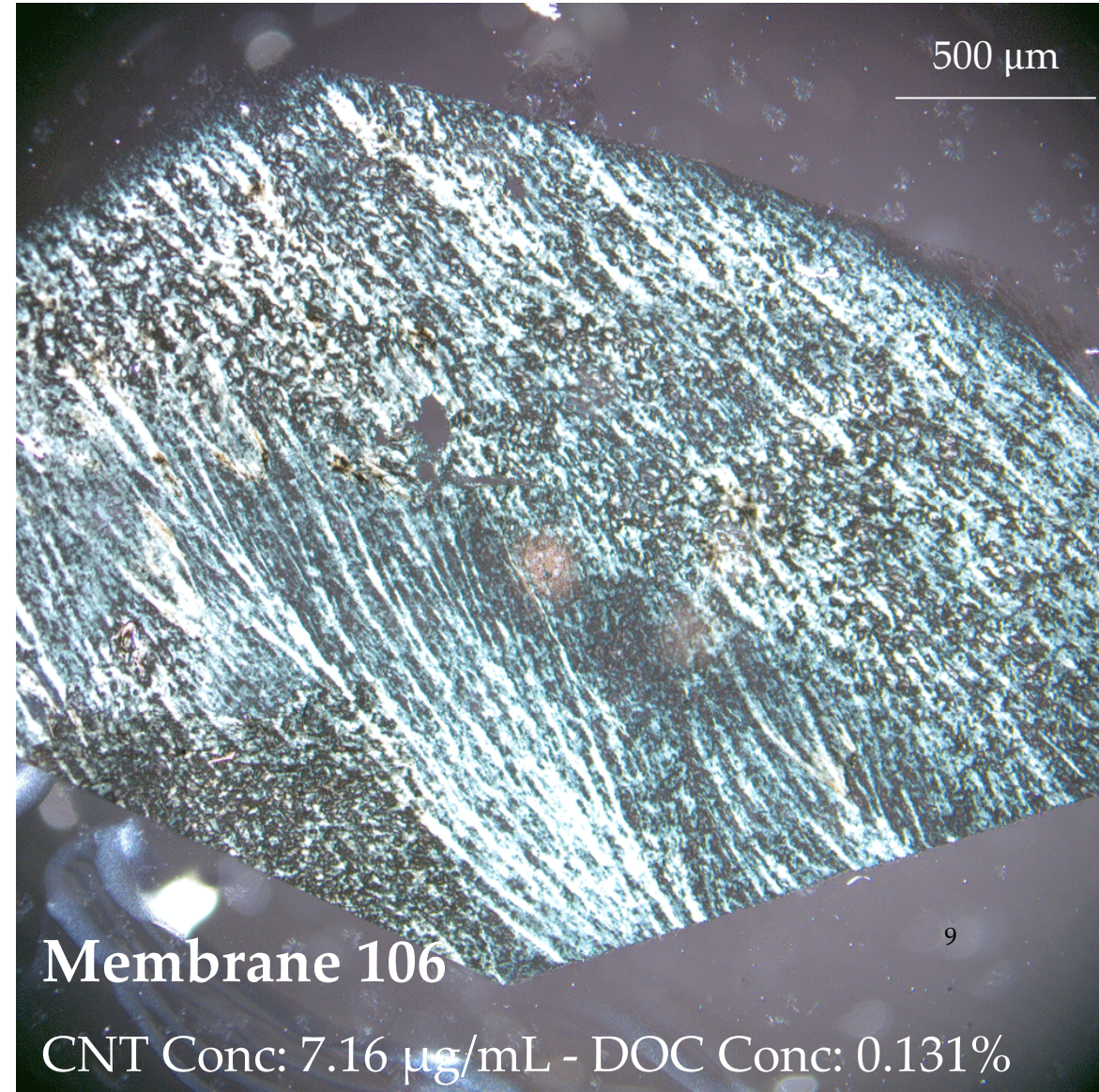
Qualitative Alignment Assessment Polarized Optical Microscopy



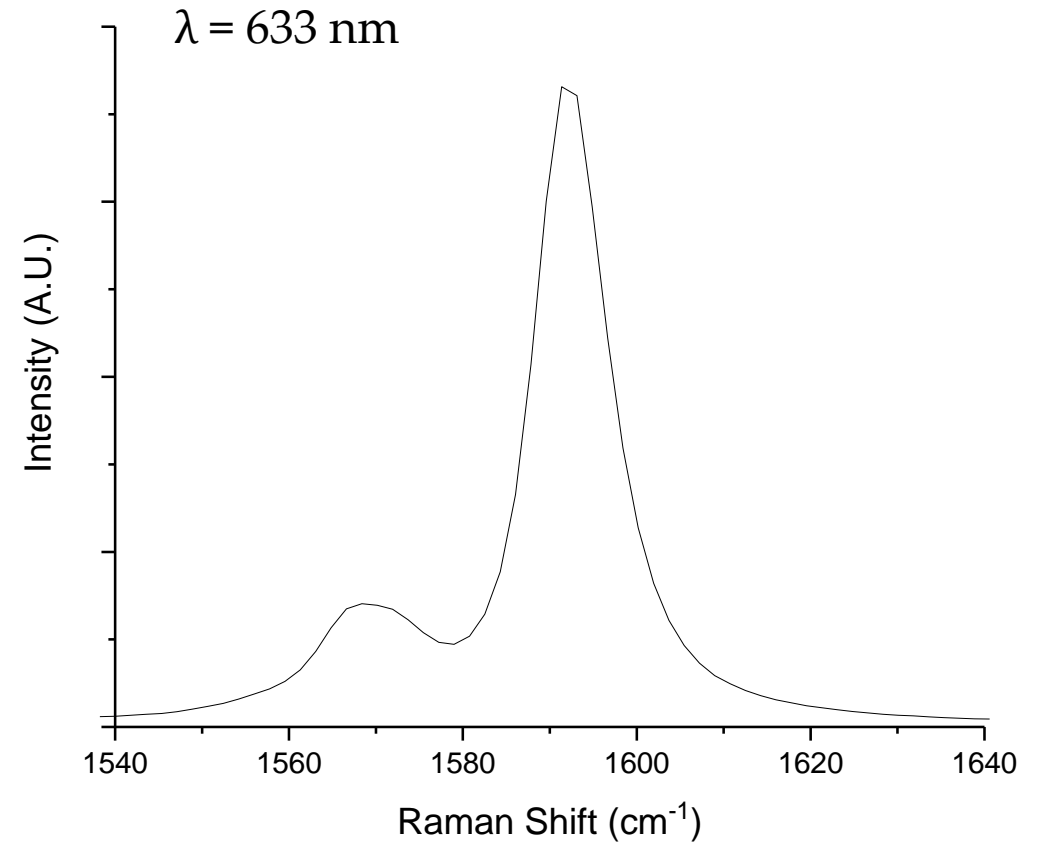
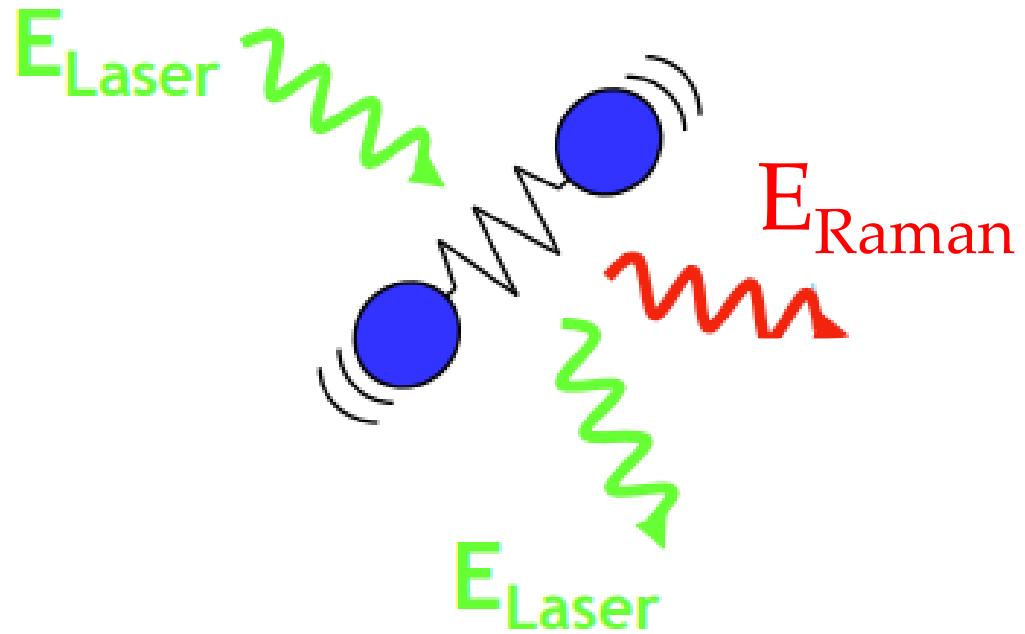
Qualitative Results: Polarized Optical Microscopy



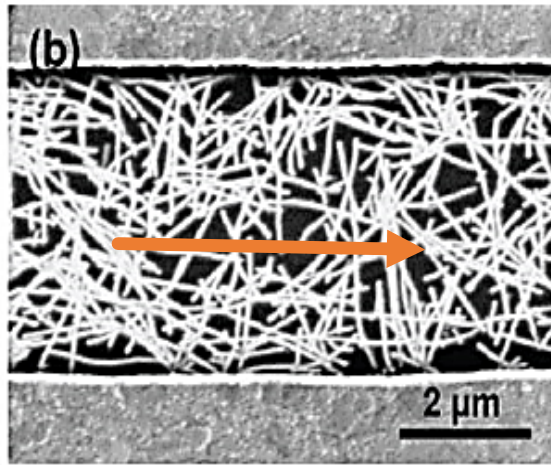
Delta
CNT: 2.8
DOC:0.05



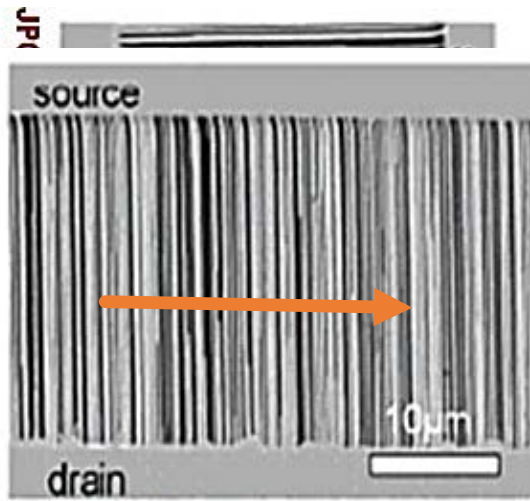
Raman Spectroscopy



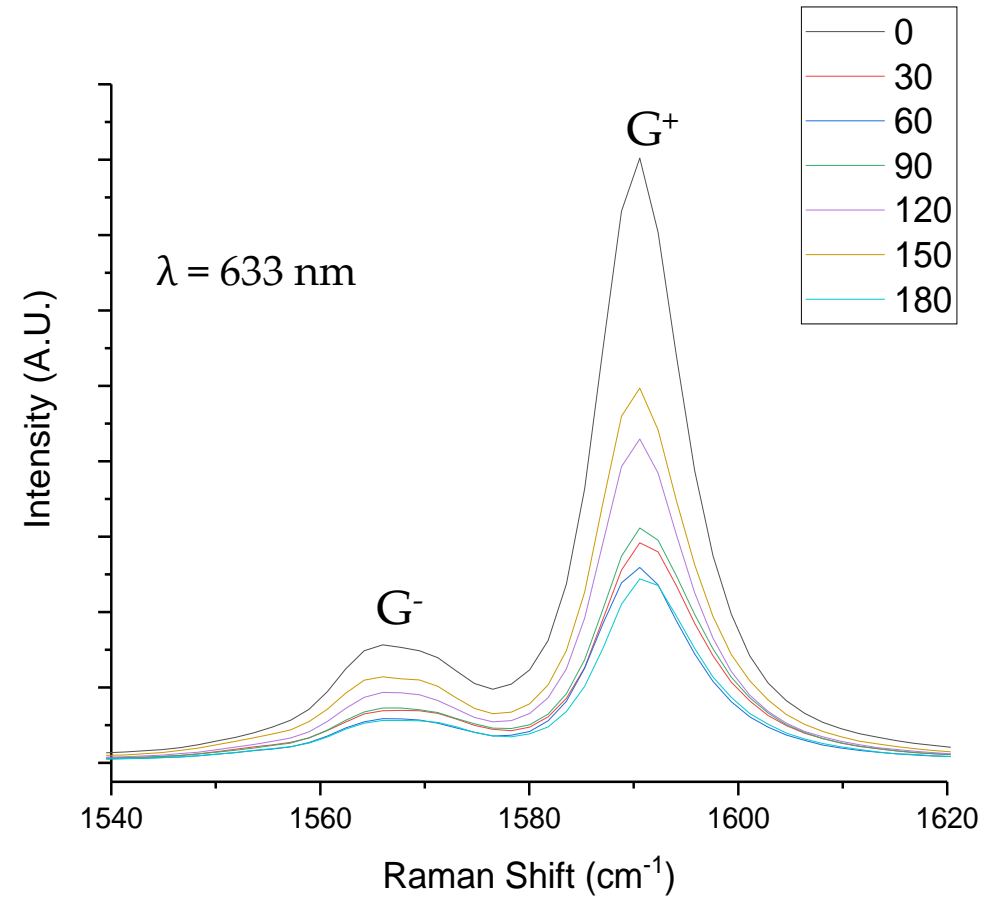
Raman Sensitivity to Alignment



NL9(2009)4285 by C. Zhou Group

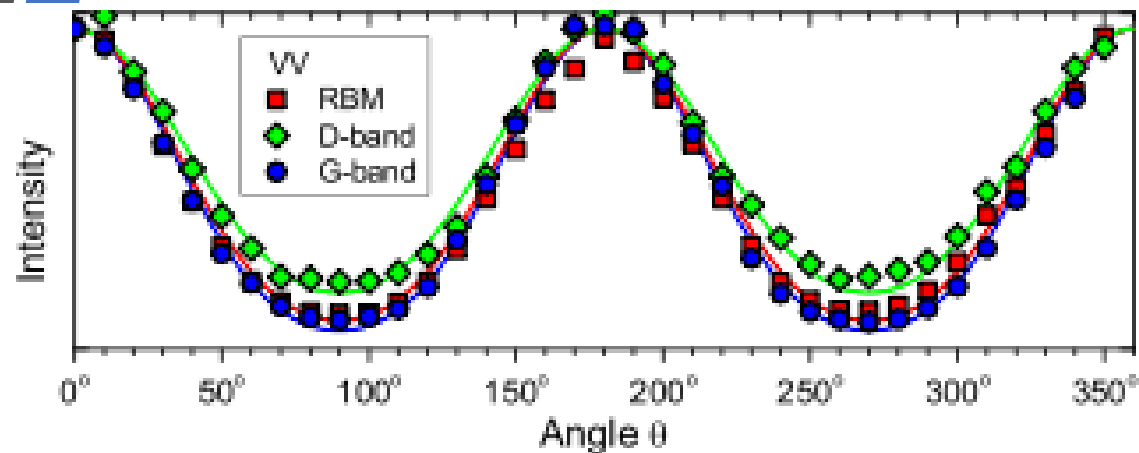


JPCC111(2007)17879 by A. Rogers Group

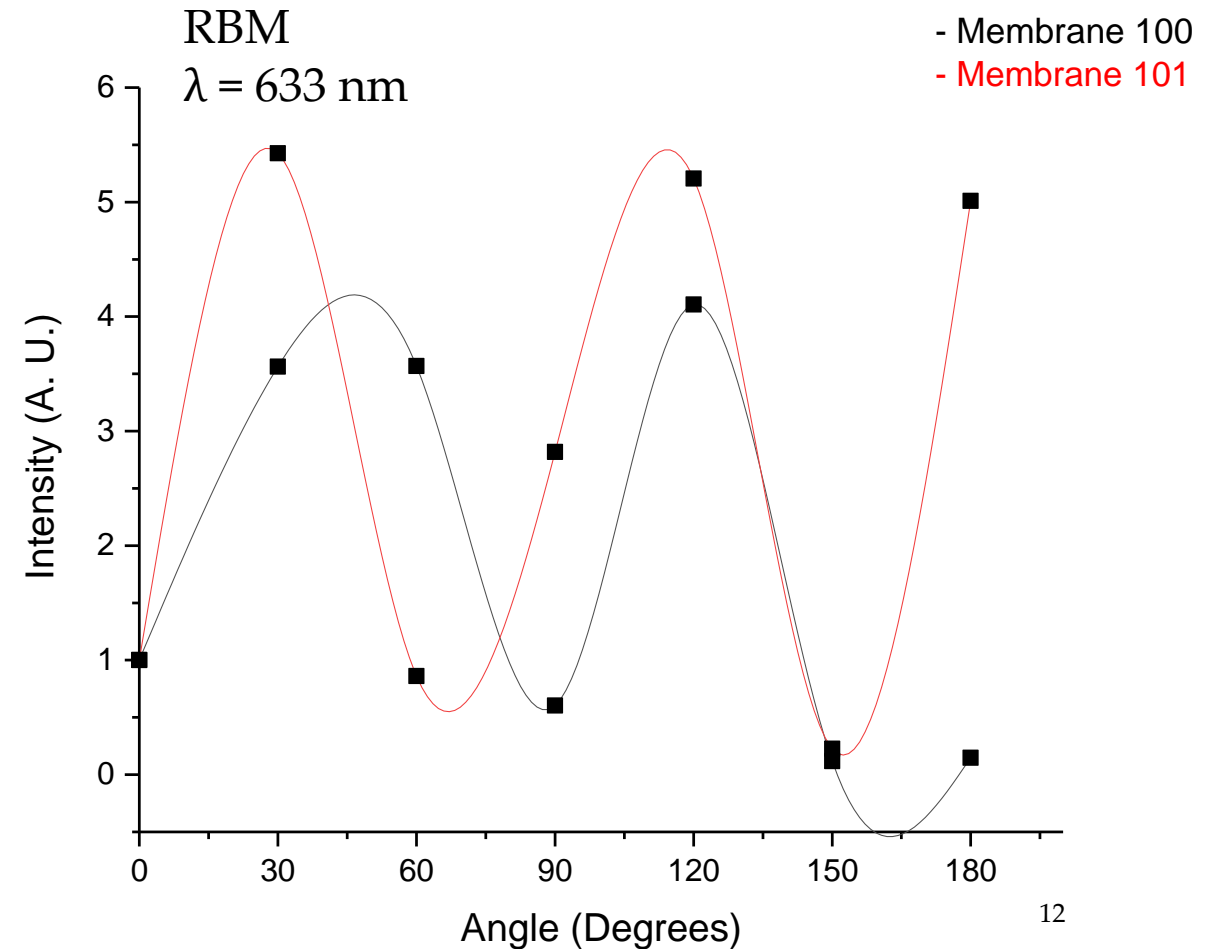


Quantitative Results: Polarized Raman

Sinusoidal curve



Fagan, J. A., et al. *PRL*. 98.14 (2007): 147402.



Quantitative Results: Nematic Order Parameter

Membrane	I_{VV}/I_{HH}	SWCNT Concentration ($\mu\text{g/mL}$)	DOC Concentration (%)
106	9.21	7.19	0.13

$$S_{Raman} = \frac{6\Delta I_{VV} + 3(1 + \Delta)I_{VH} - 8I_{HH}}{6\Delta I_{VV} + 12(1 + \Delta)I_{VH} - 16I_{HH}}$$

S_{Raman} of Membrane 106 is 0.86

Conclusion

- Established a new NIST capability
- Successfully produced several large area, highly aligned SWCNTs films
- Mastered characterization methods: optical cross polarization and polarized Raman spectroscopy

Acknowledgements

Postdocs

Heather Hill



Adam Biacchi



Amber McCreary



Project Leaders

Angela Hight Walker



Jeff Fagan



Guest Researchers

Guangjun Cheng



Erin Wood



Questions?

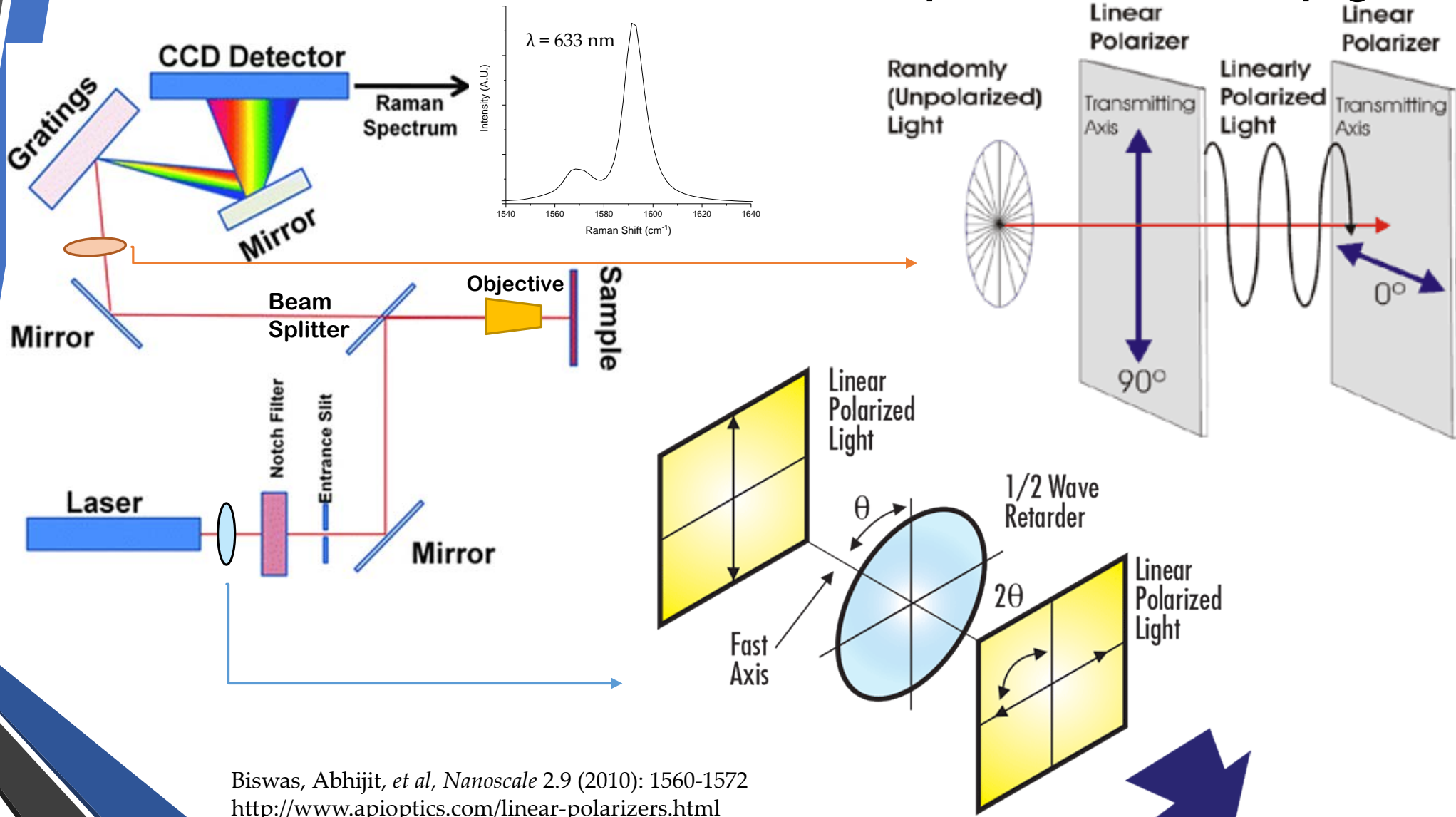
Thank you



Next Steps

- Investigate how does filled SWCNT, other than water, affect the alignment
- How the polycarbonate membrane affects the alignment
- Optimizing the protocol to create monodomain alignment films

Polarized Raman Spectroscopy

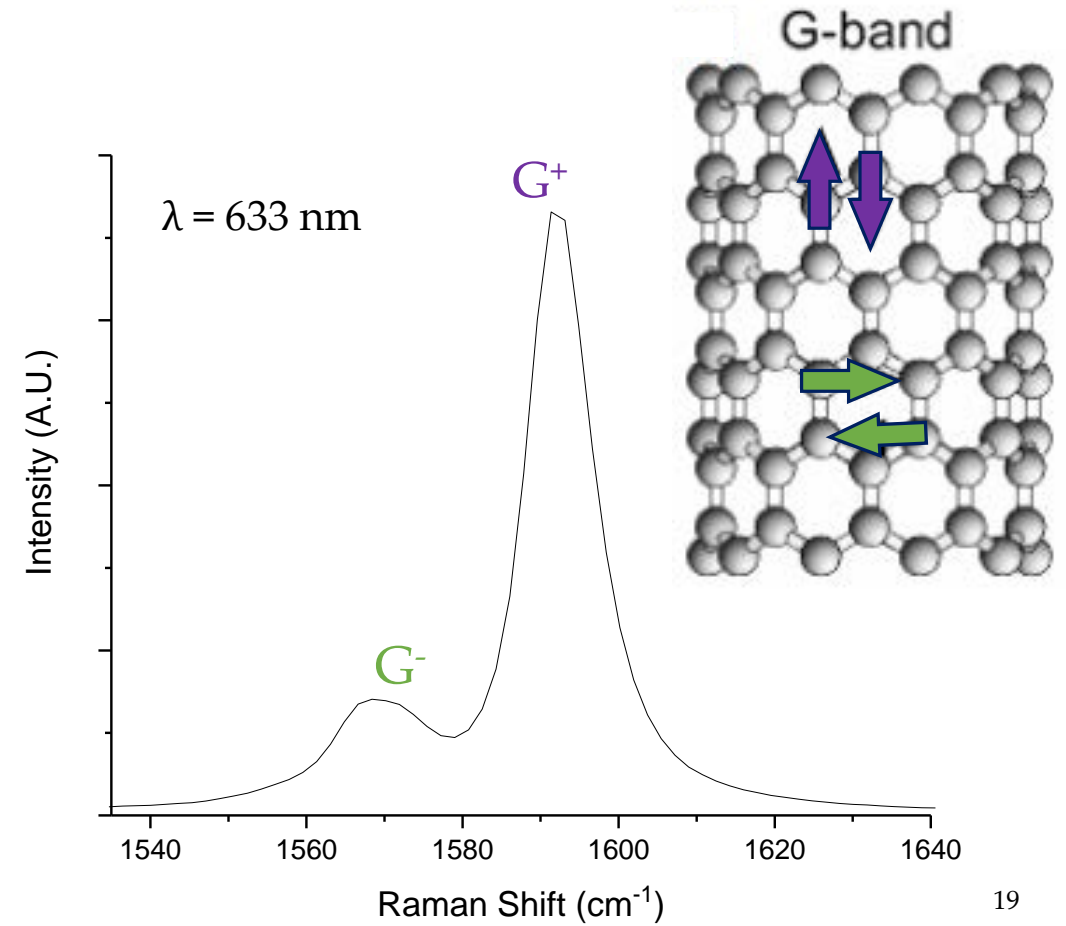
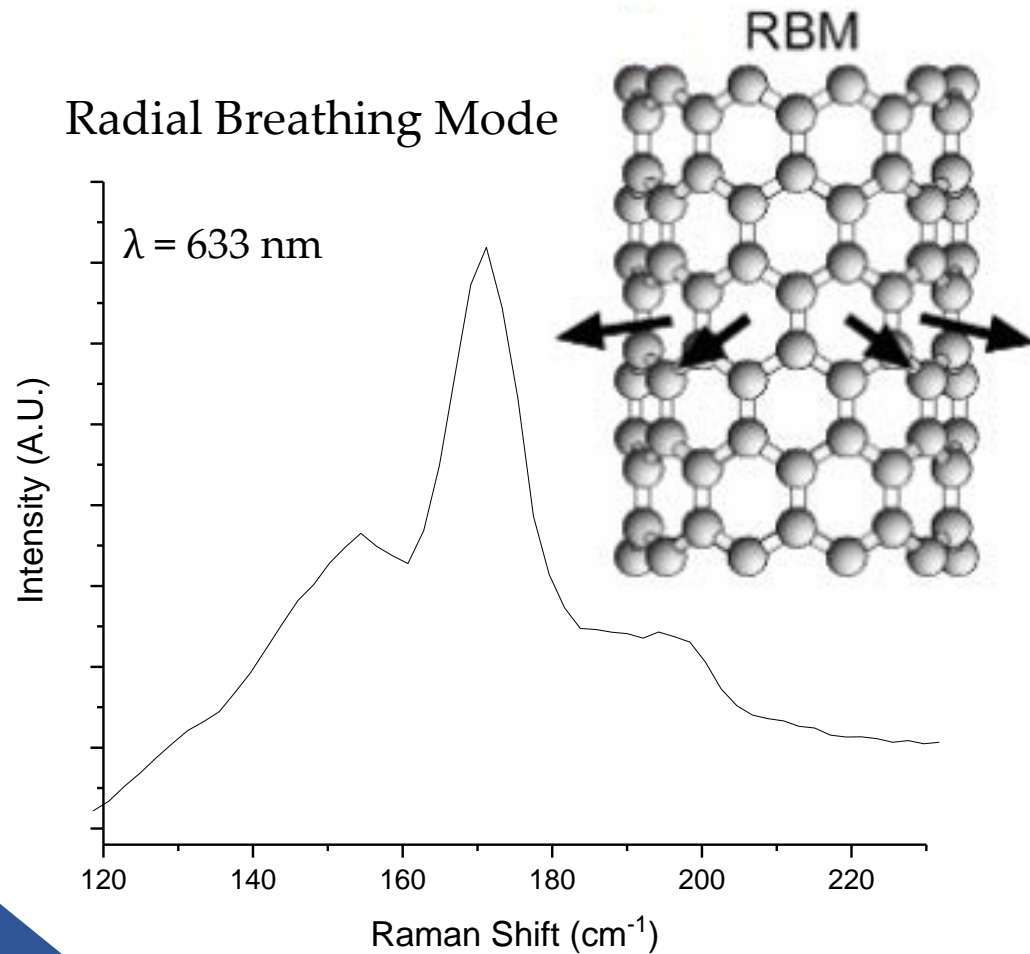


Biswas, Abhijit, *et al*, *Nanoscale* 2.9 (2010): 1560-1572

<http://www.apioptics.com/linear-polarizers.html>

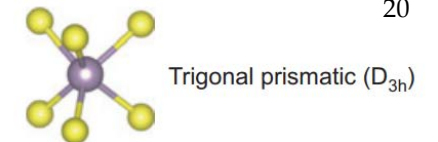
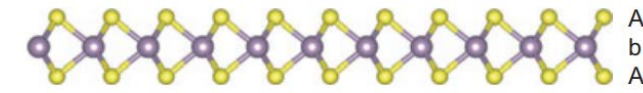
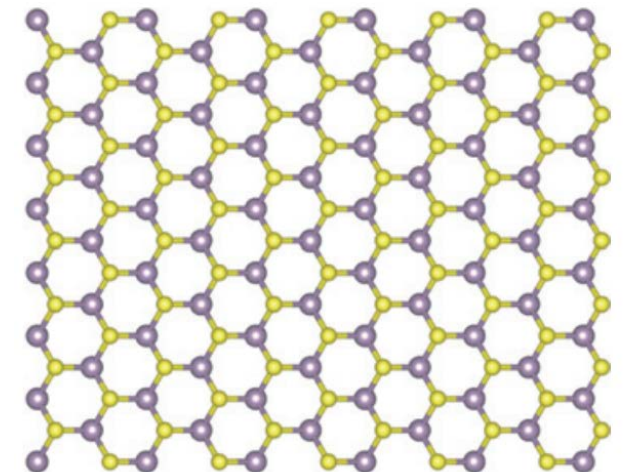
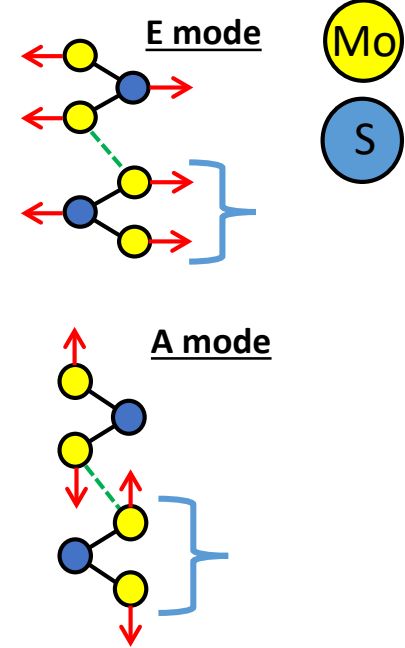
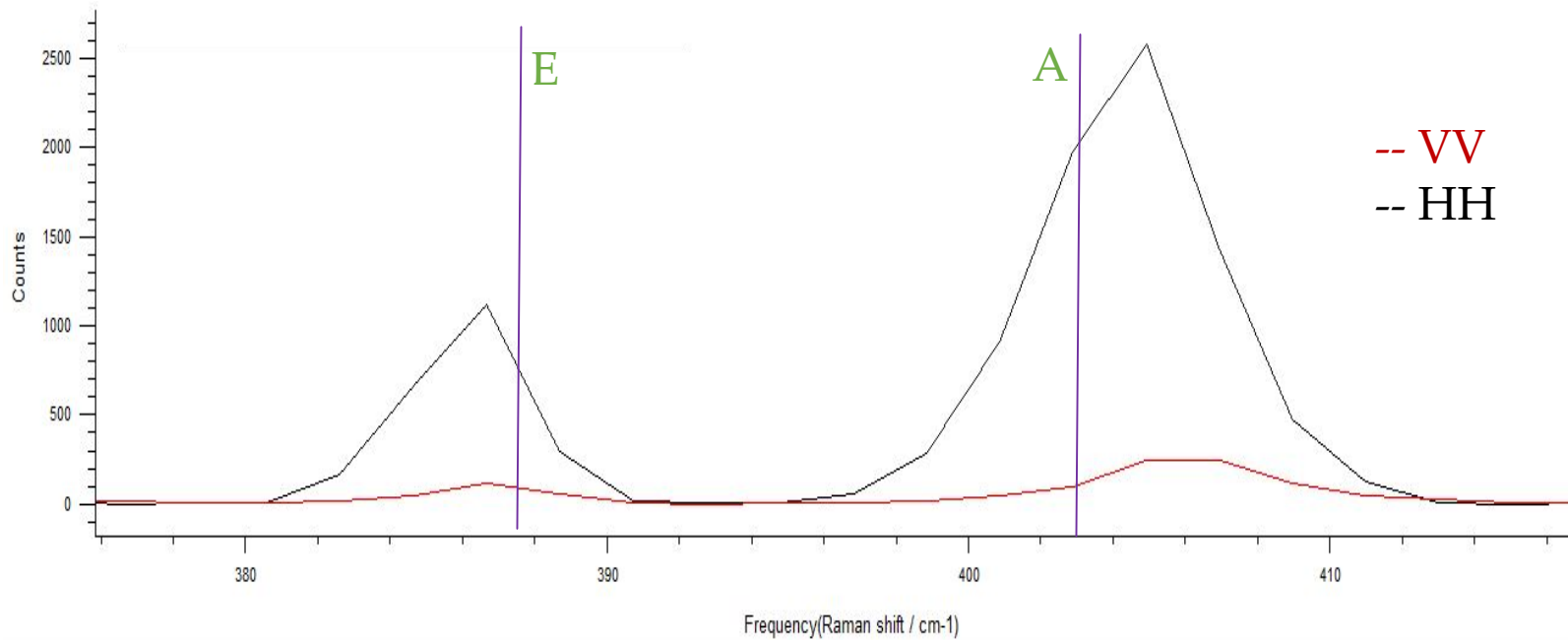
<https://www.edmundoptics.com/resources/application-notes/optics/understanding-waveplates/>

Raman Spectra of SWCNTs



Spectrometer Sensitivity

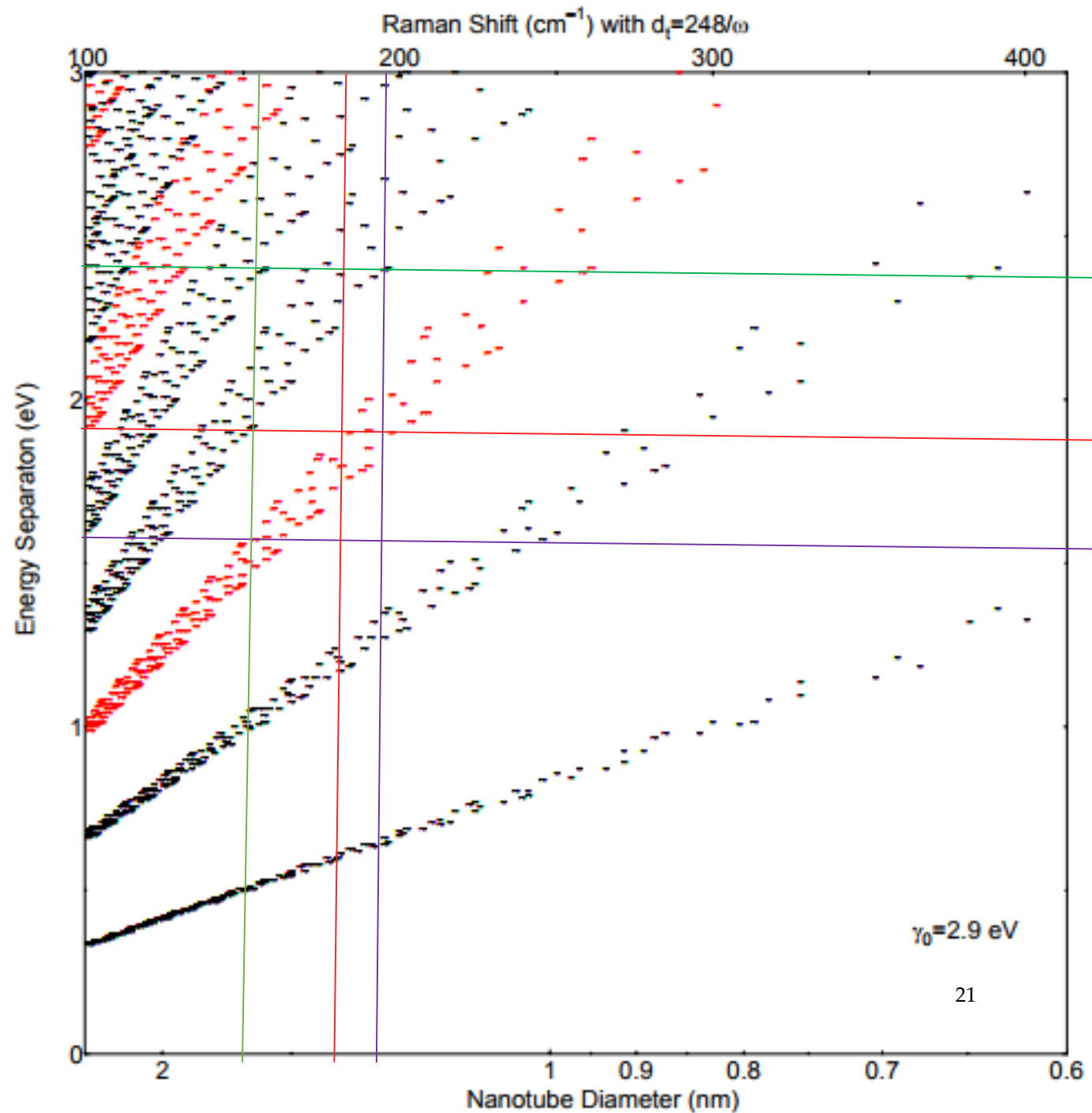
MoS₂ Sample
514 nm

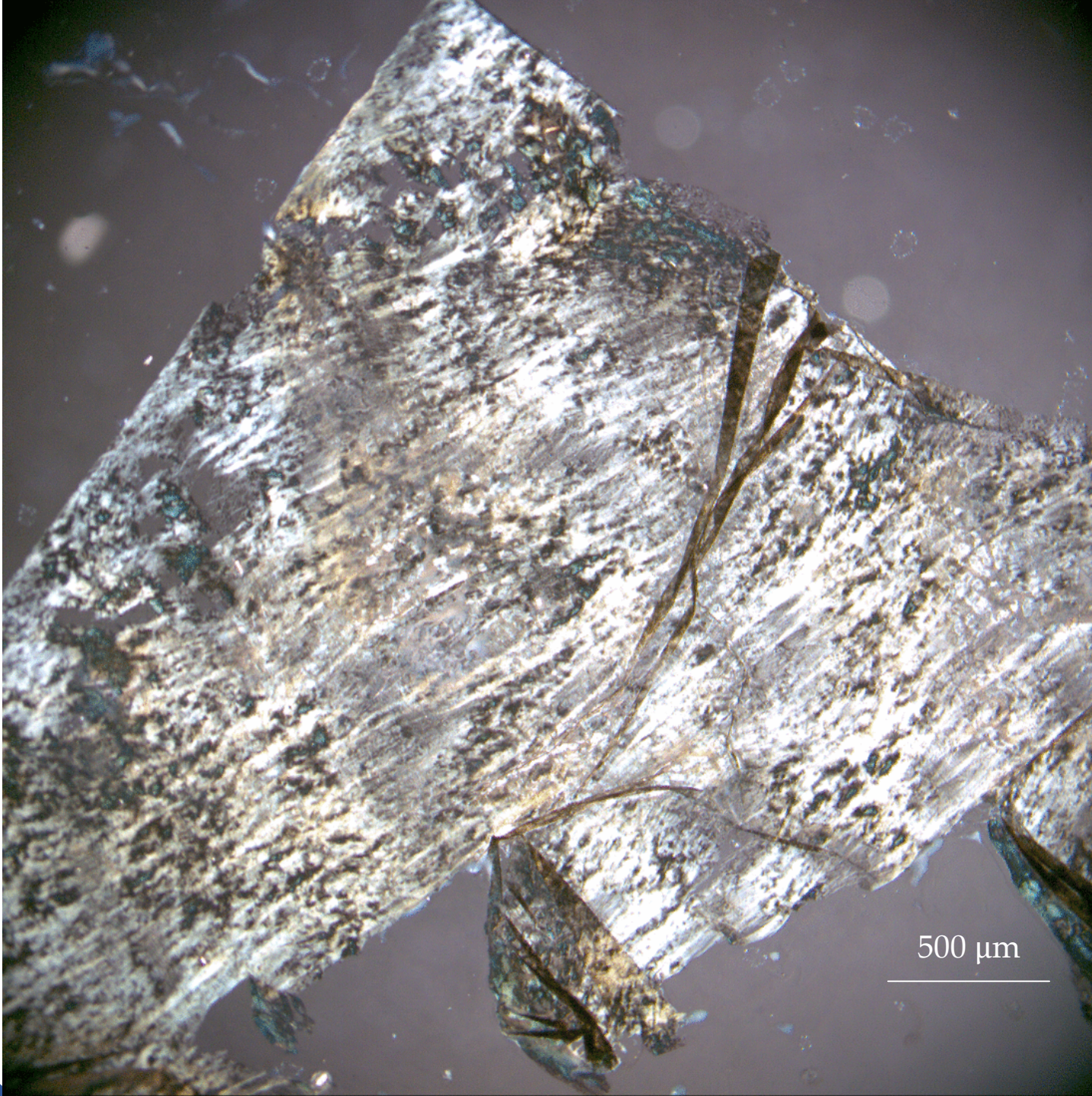
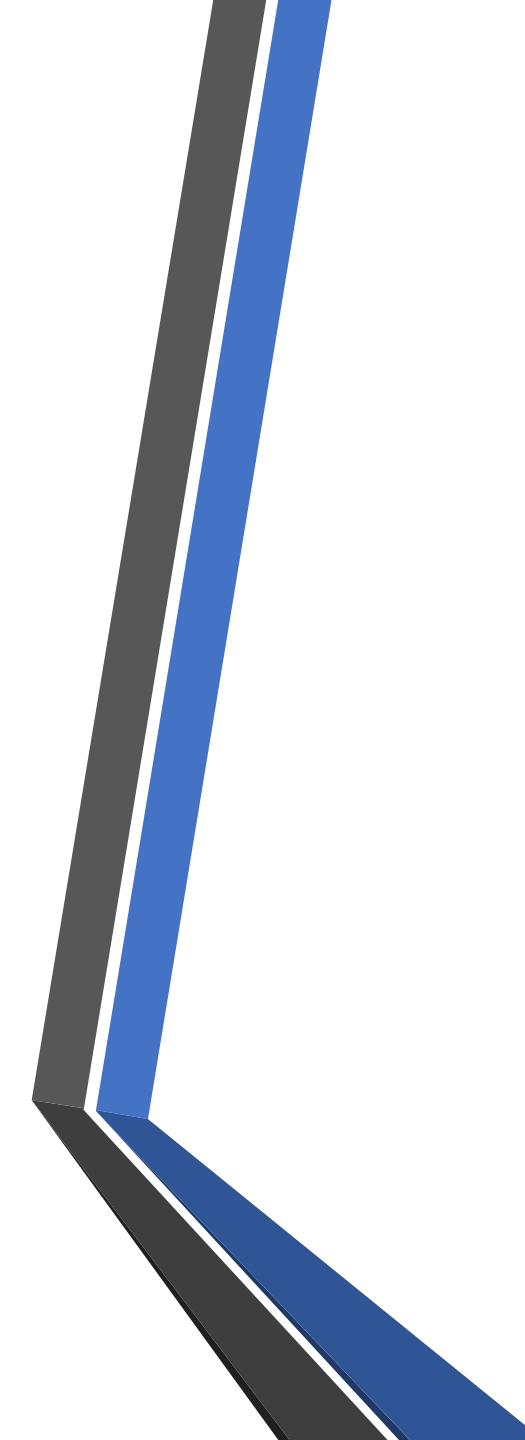


VV	HH	Ratio
127.834	1517.04	0.079
310.57	2801.46	0.111

Assignment of Chirality of Tubes

- 514 nm = 2.412 eV
 - (11,9)
- 633 nm = 1.959 eV
 - (14,5)
- 785 nm = 1.579 eV
 - (19,3)





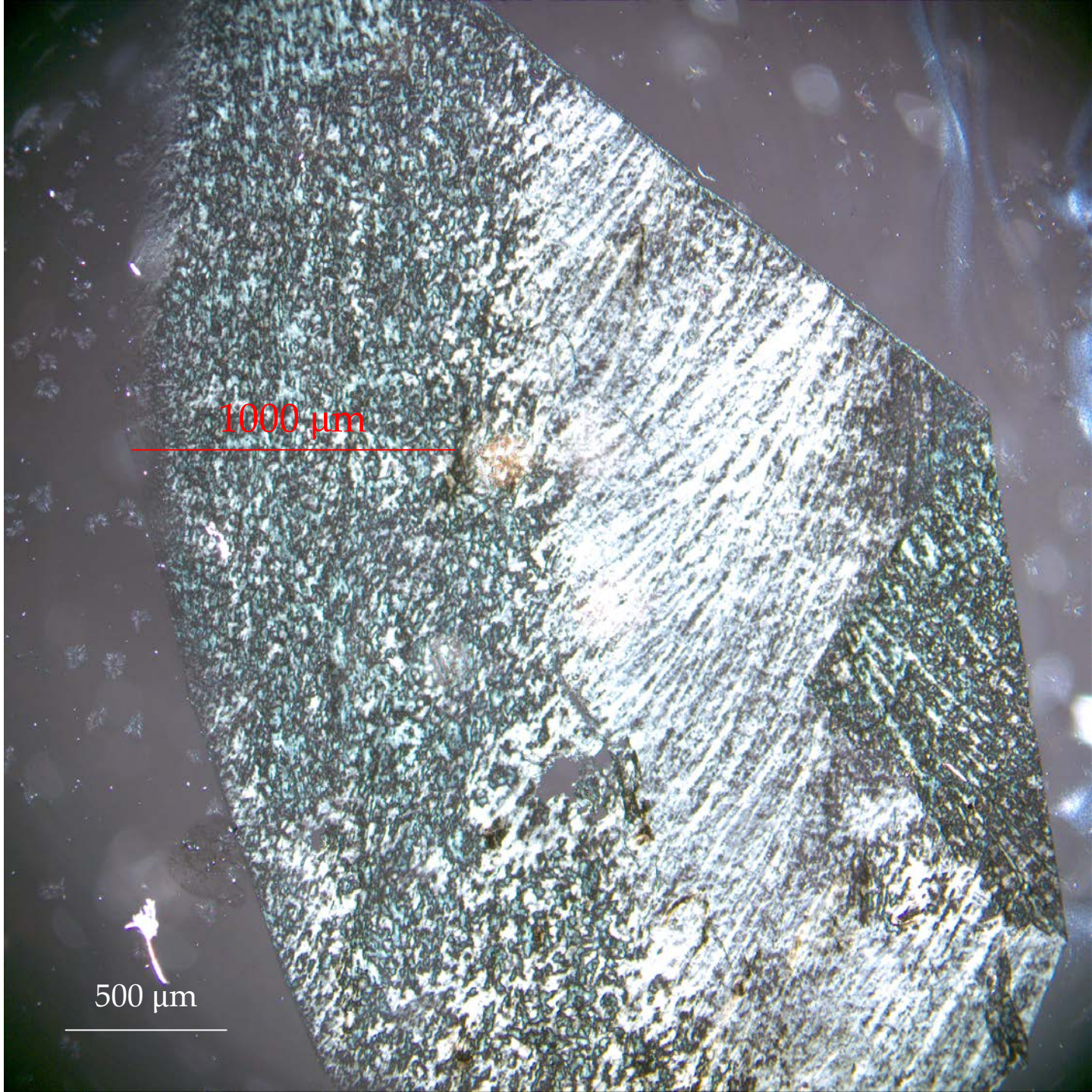
Membrane 105

CNT Conc: 5.53 $\mu\text{g}/\text{mL}$

DOC Conc: 1.01%

Alignment: $\sim 500\mu\text{m}$

Substrate: Glass



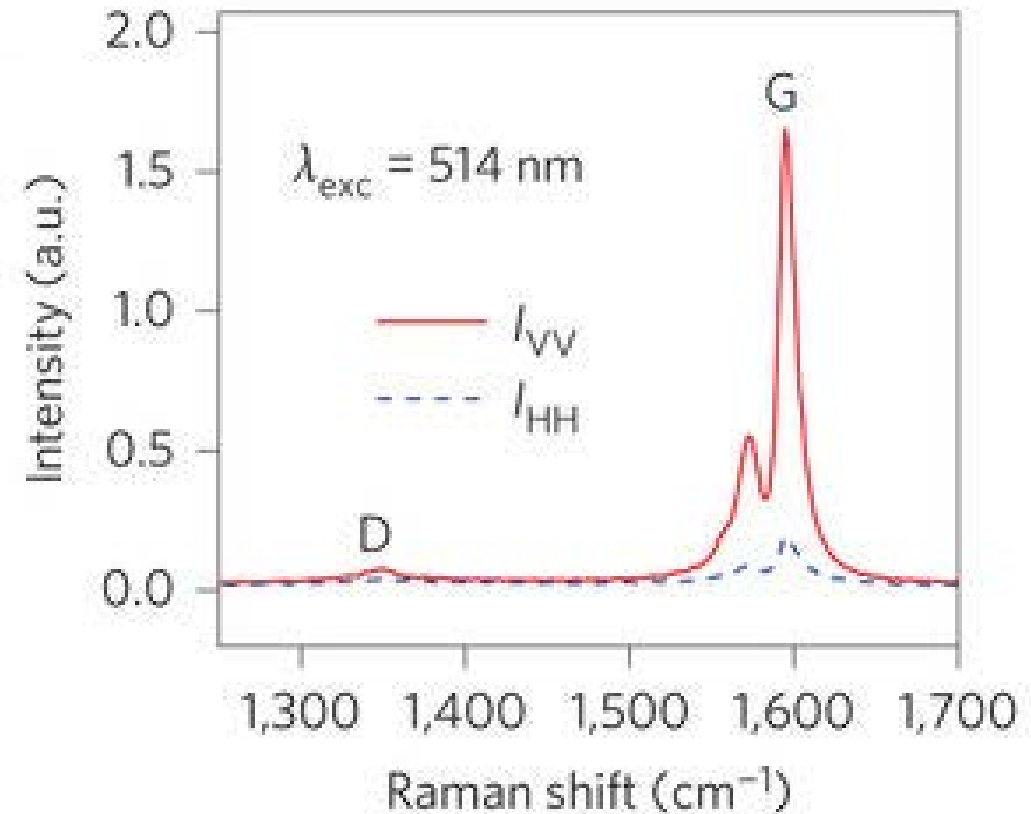
1000 μm

500 μm

Polarized Raman Spectroscopy

Assess the quality of alignment i.e. determine the nematic order parameter S

$$S_{Raman} = \frac{6\Delta I_{VV} + 3(1 + \Delta)I_{VH} - 8I_{HH}}{6\Delta I_{VV} + 12(1 + \Delta)I_{VH} - 16I_{HH}}$$



Absorption

