Creation and Characterization of Aligned Single-Walled Carbon Nanotube Films

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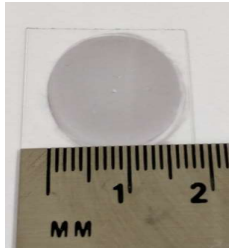

- A general understanding of Single-Walled Carbon Nanotubes (SWCNT)
- The importance of nanotube alignment
- Process that is used for nanotube alignment
- Demonstration of alignment in nanotube films

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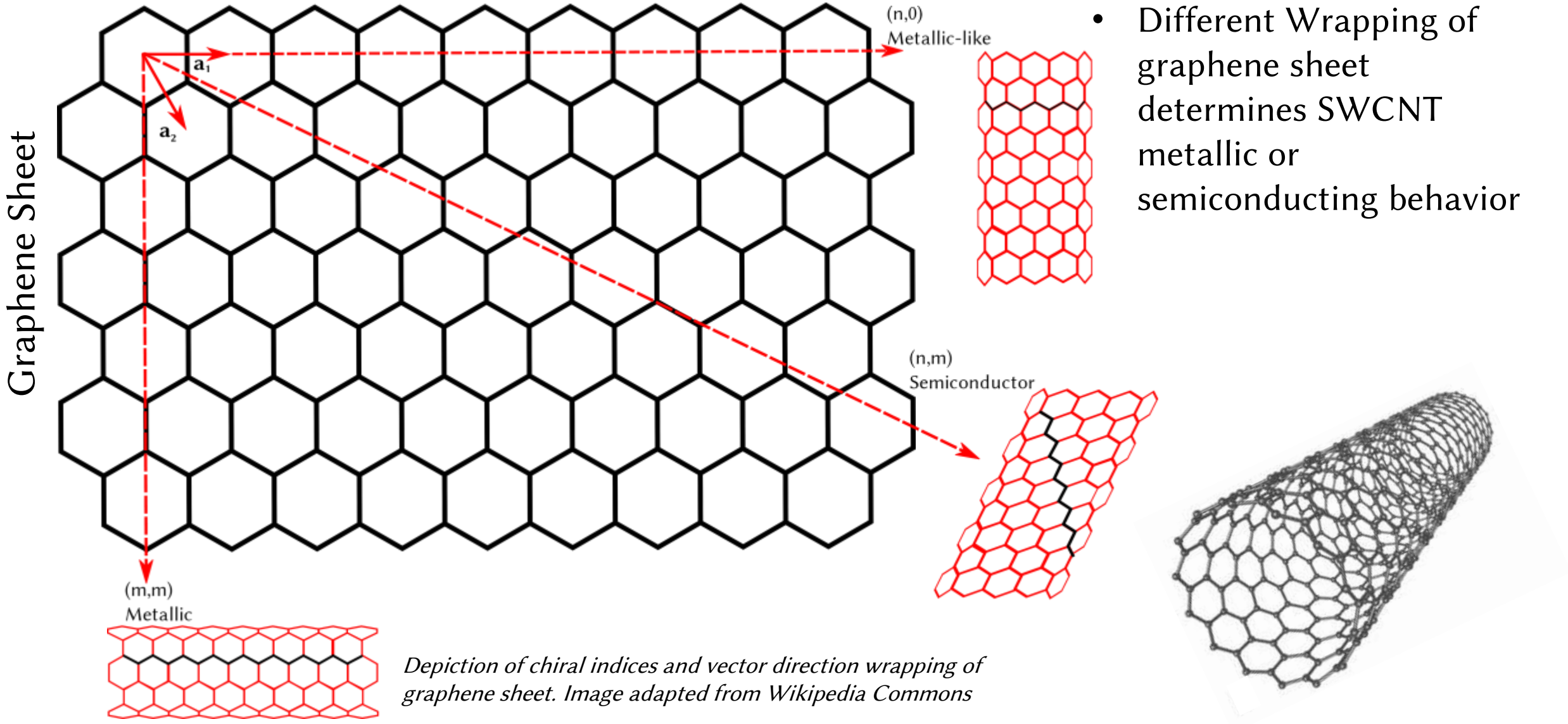
Single-Walled Carbon Nanotubes



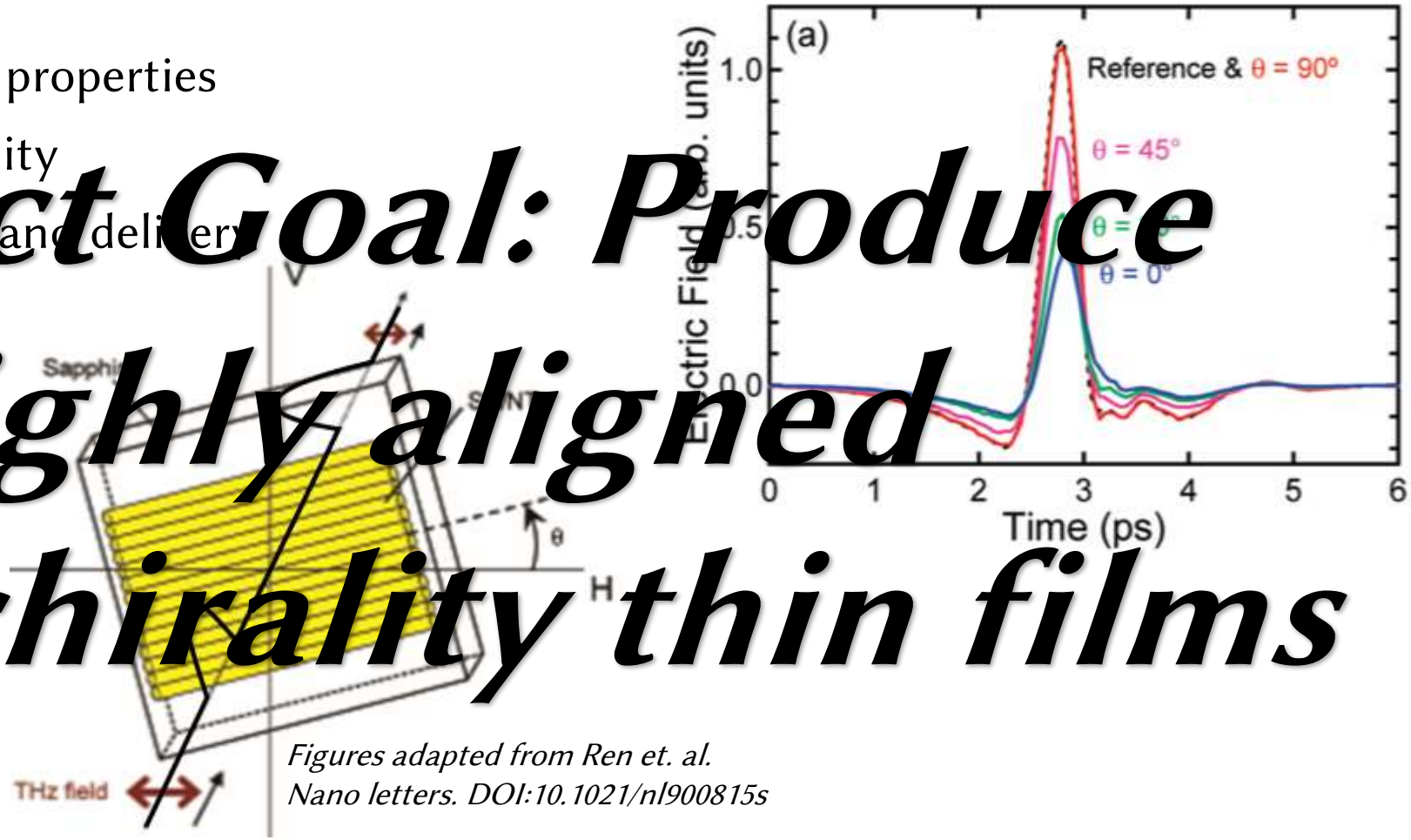
- Different Wrapping of graphene sheet determines SWCNT metallic or semiconducting behavior

Depiction of chiral indices and vector direction wrapping of graphene sheet. Image adapted from Wikipedia Commons

Advantage to SWCNT Alignment

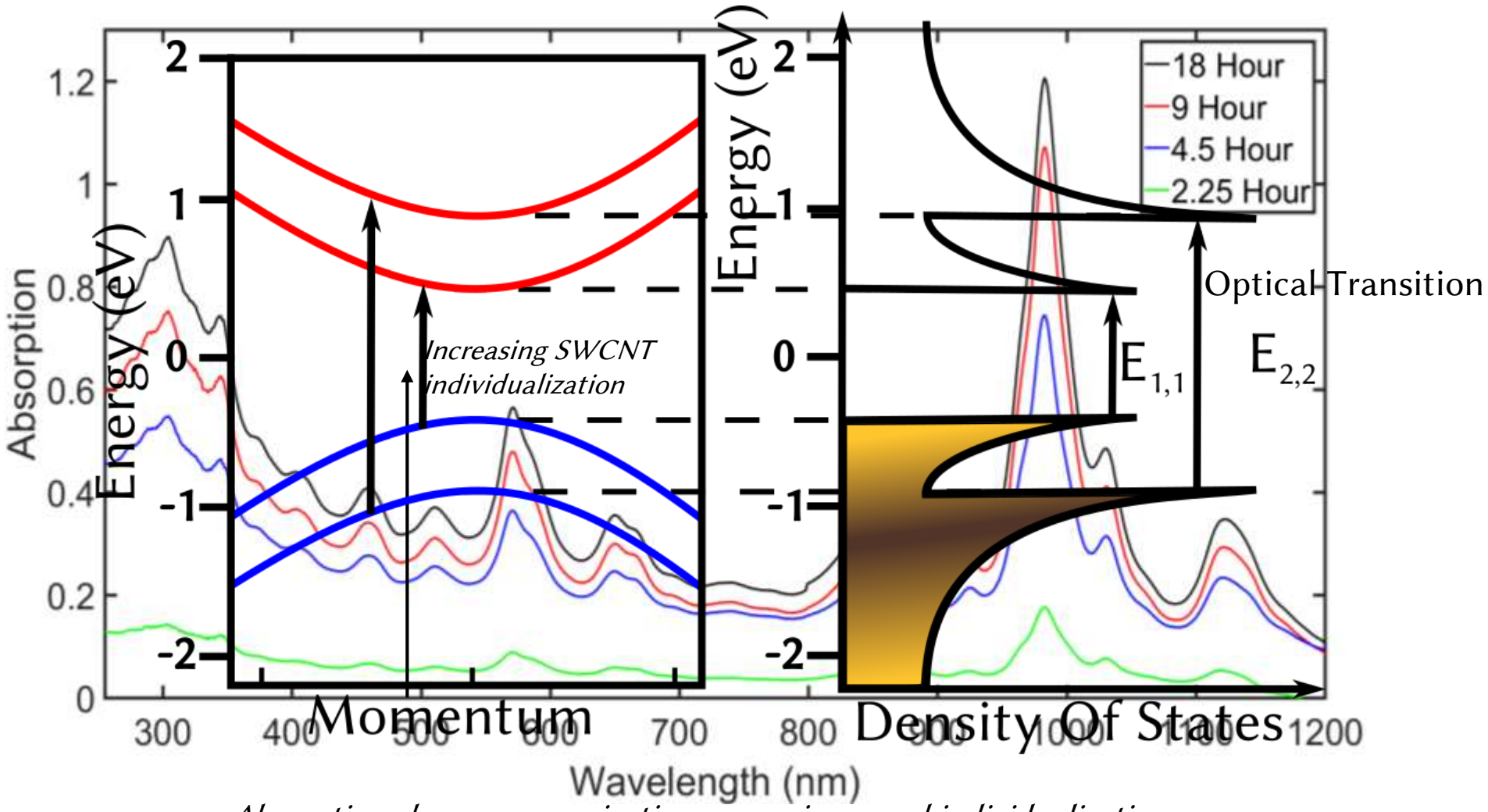
- Interesting anisotropic properties
- Quasi one-dimensionality
- Electrical conductivity and delivery
- Terahertz polarizer

Project Goal: Produce highly aligned single chirality thin films



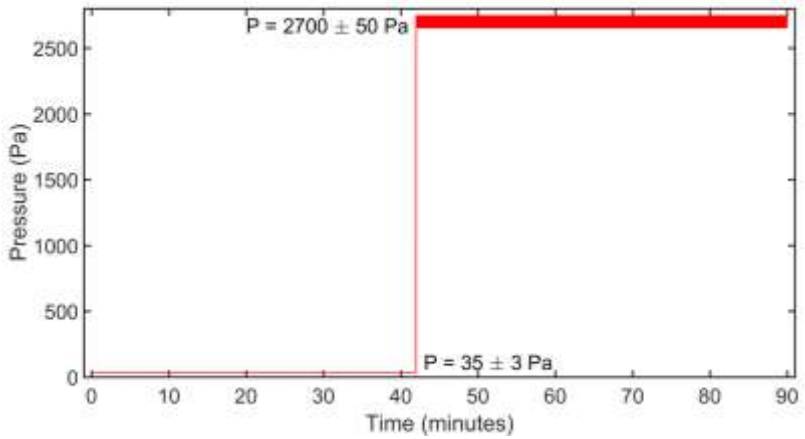
Figures adapted from Ren et. al. Nano letters. DOI:10.1021/nl900815s

SWCNT Individualization



Absorption changes as sonication causes increased individualization

Thin Film Preparation



accuracy of differential pressure

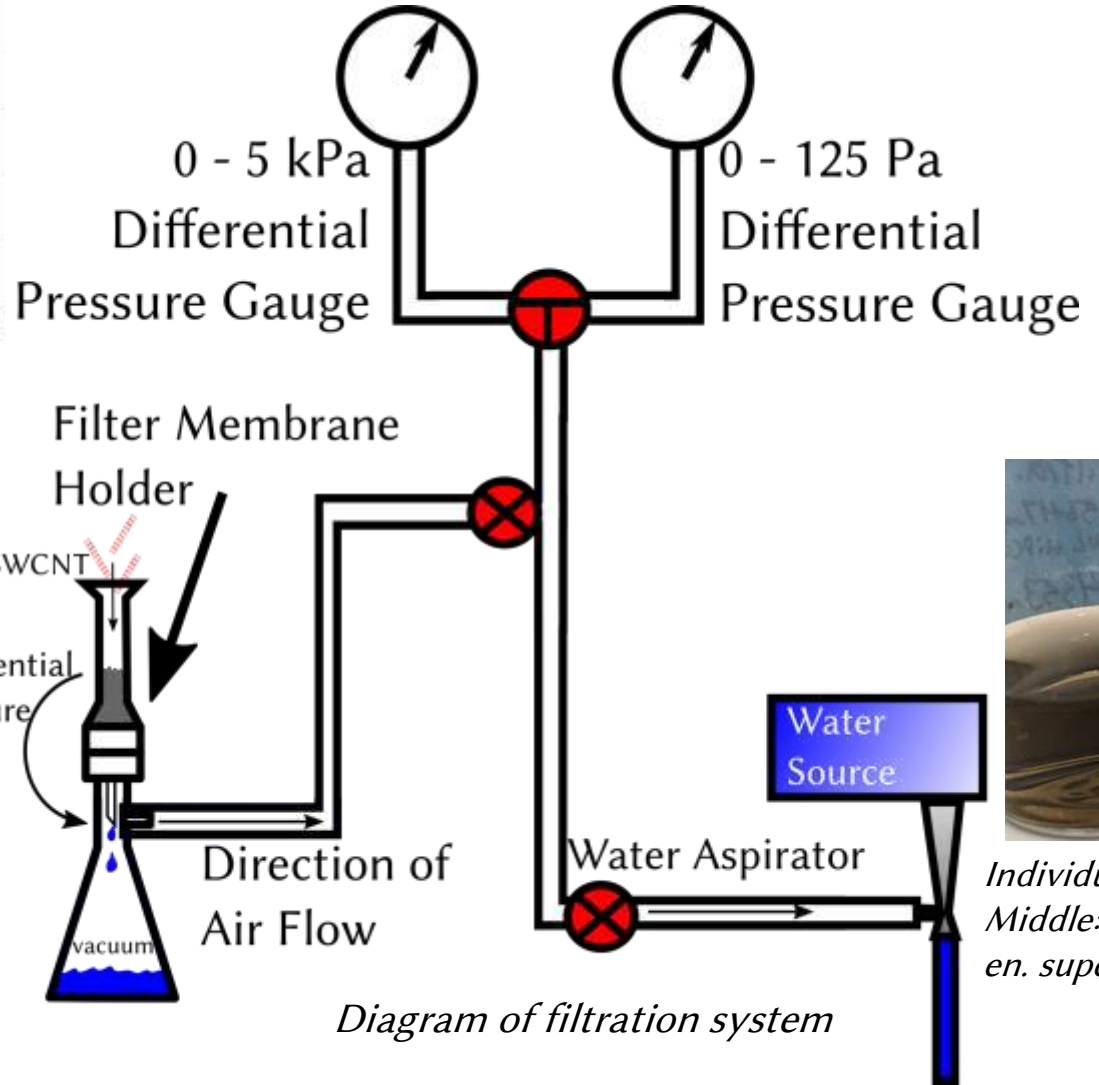


Diagram of filtration system

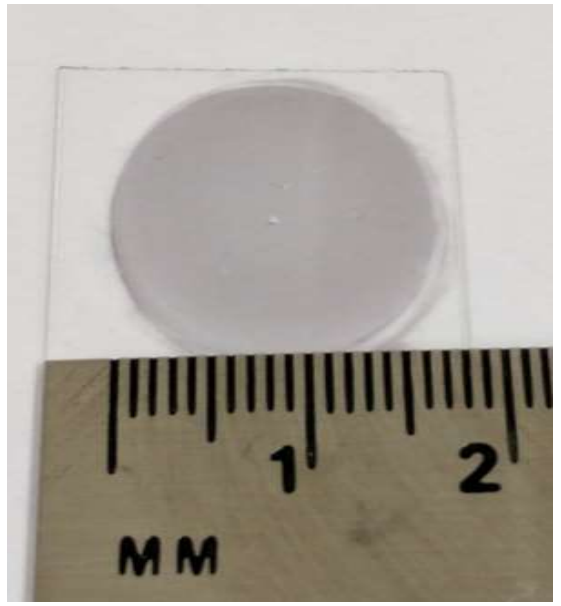
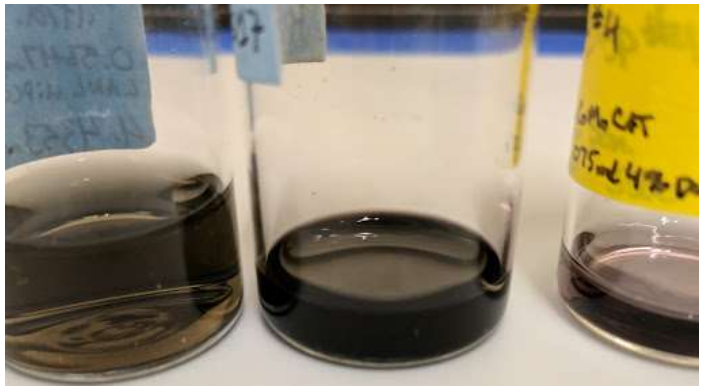


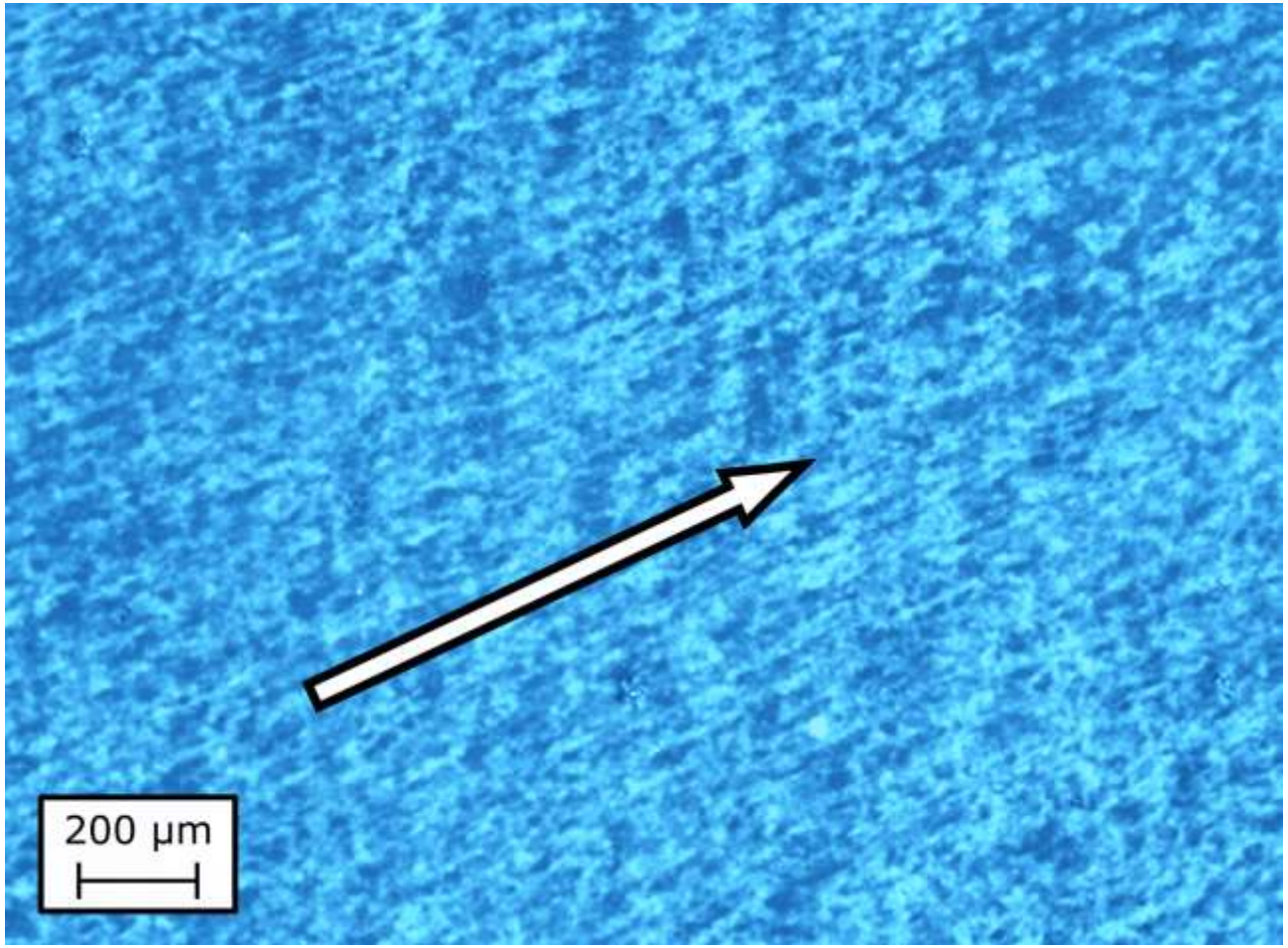
Photo of finished film



Individualized SWCNT dispersions. Left: (7,6) en. Middle: (6,5) en. supernatant. Right: Diluted (6,5) en. supernatant used for SWCNT film

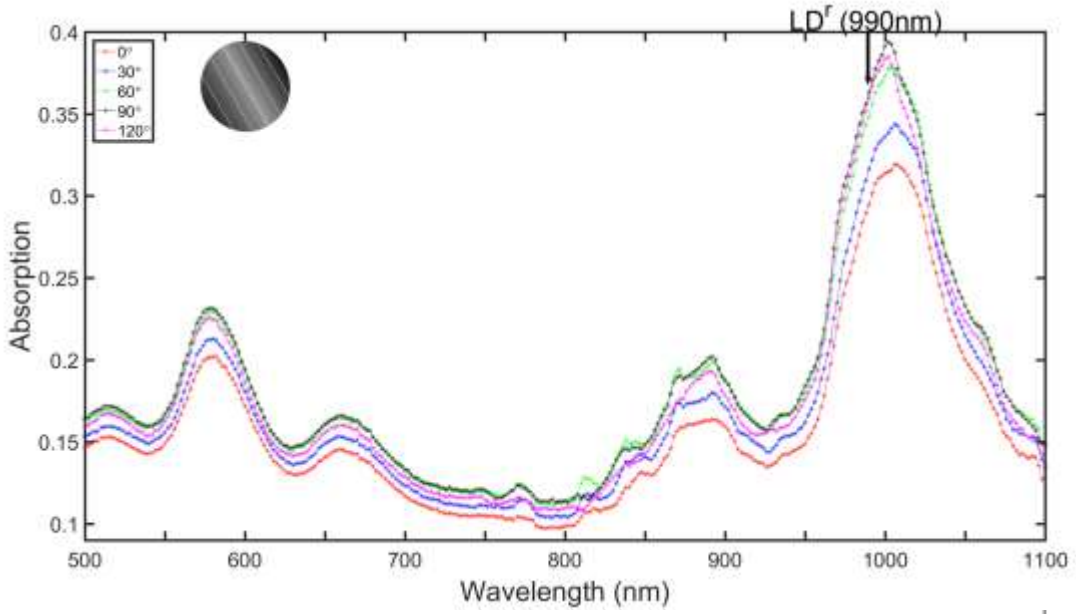
Polarized Optical Microscopy

- Uses polarized light focused on the sample
- Rotating SWCNT film qualitatively shows changes in transmission

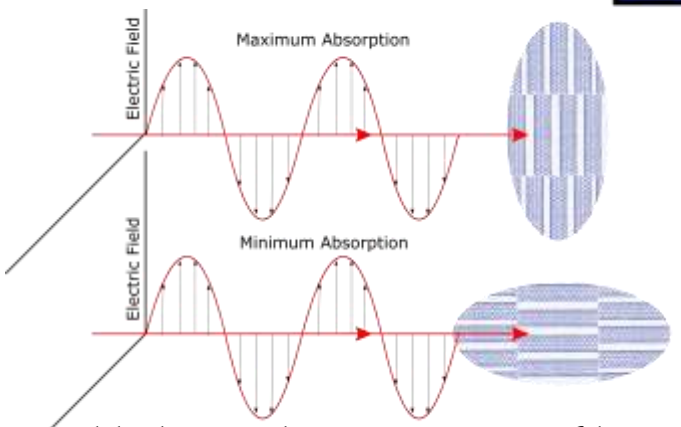


False color image of film using polarized optical microscope at 10x magnification

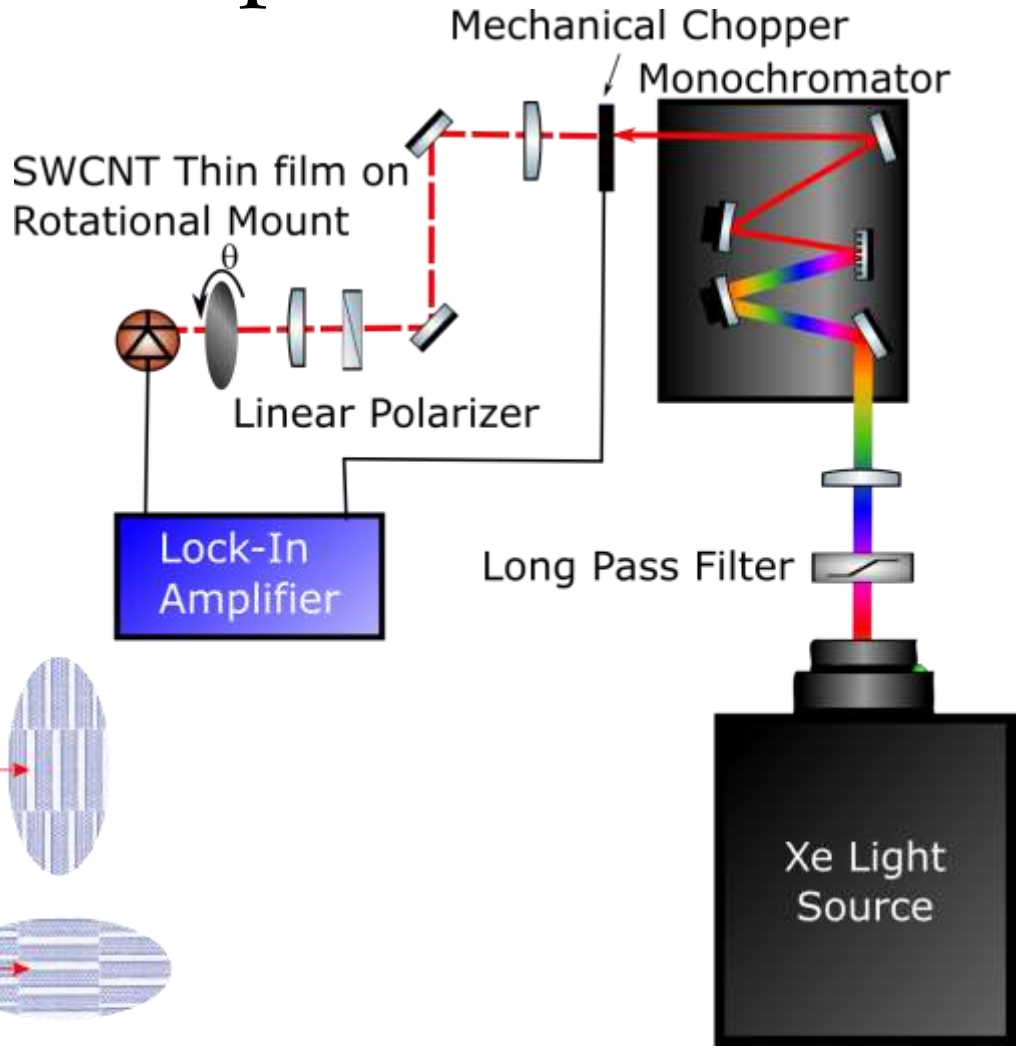
Polarized Optical Absorption



Absorption of SWCNT film

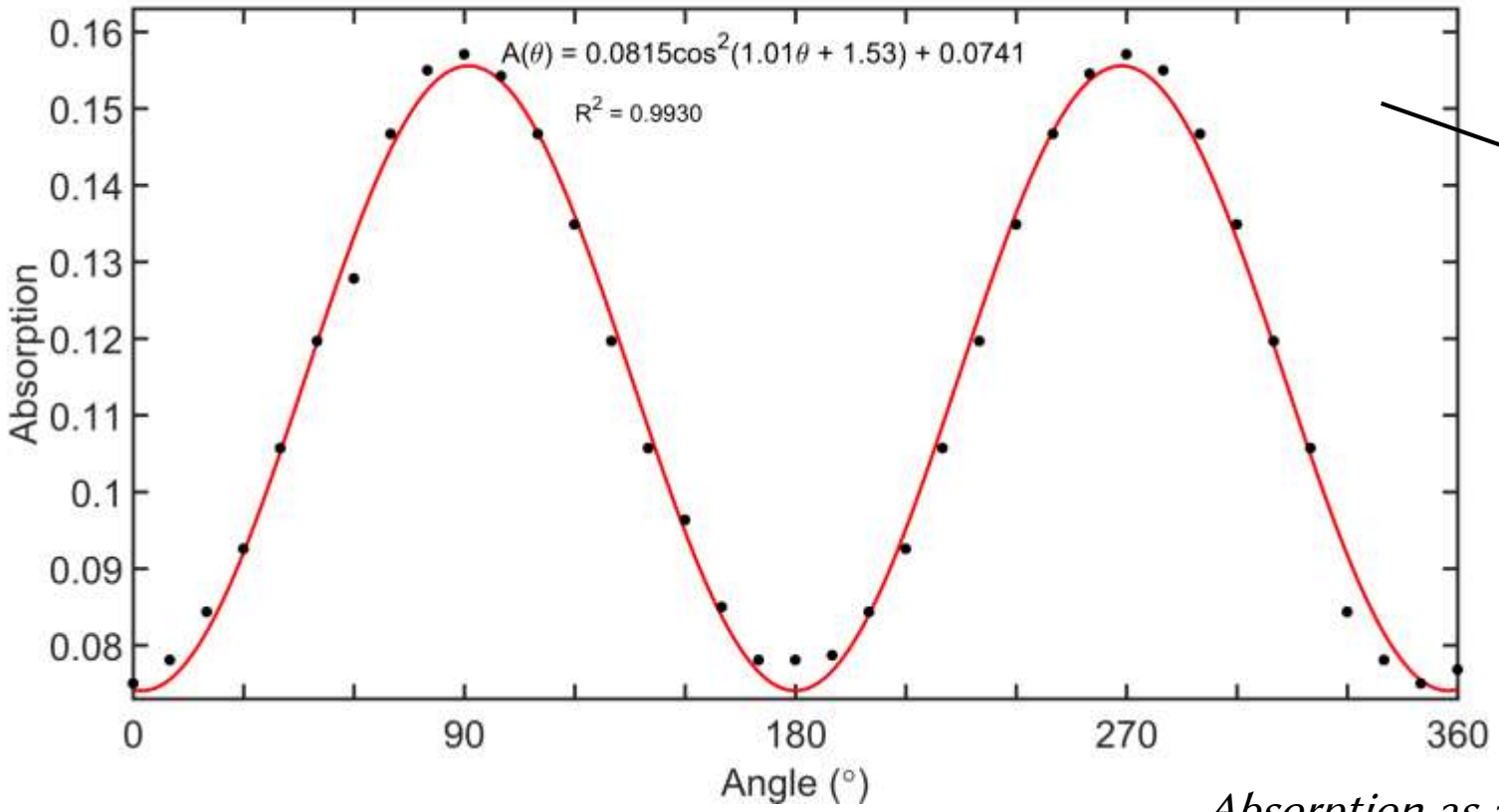


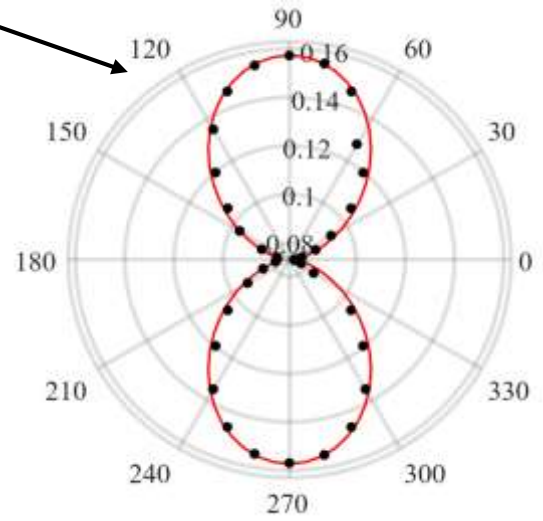
Polarized light incident on SWCNT film in maximum and minimum orientations



Schematic of polarized optical absorption experimental set up

Measurement of Nanotube Alignment



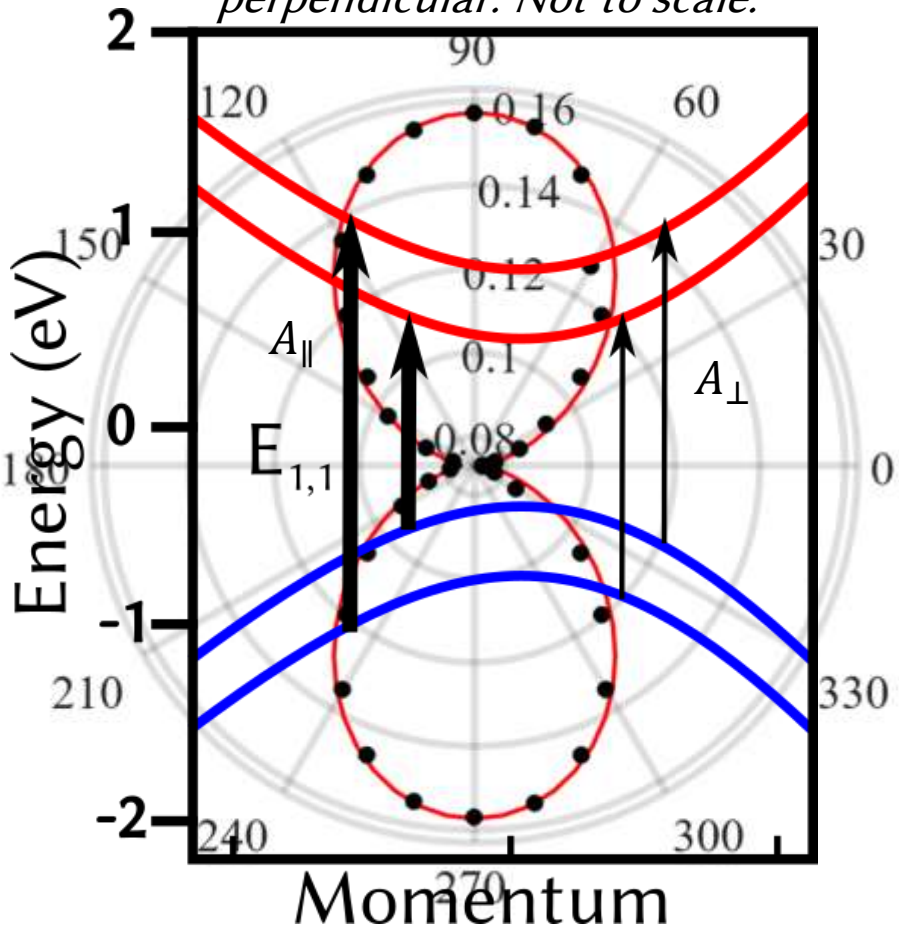


Absorption as a function of θ for SWCNT film. Regular and polar plot. Data points are black with fit line shown in red.

Reduced Linear Dichroism

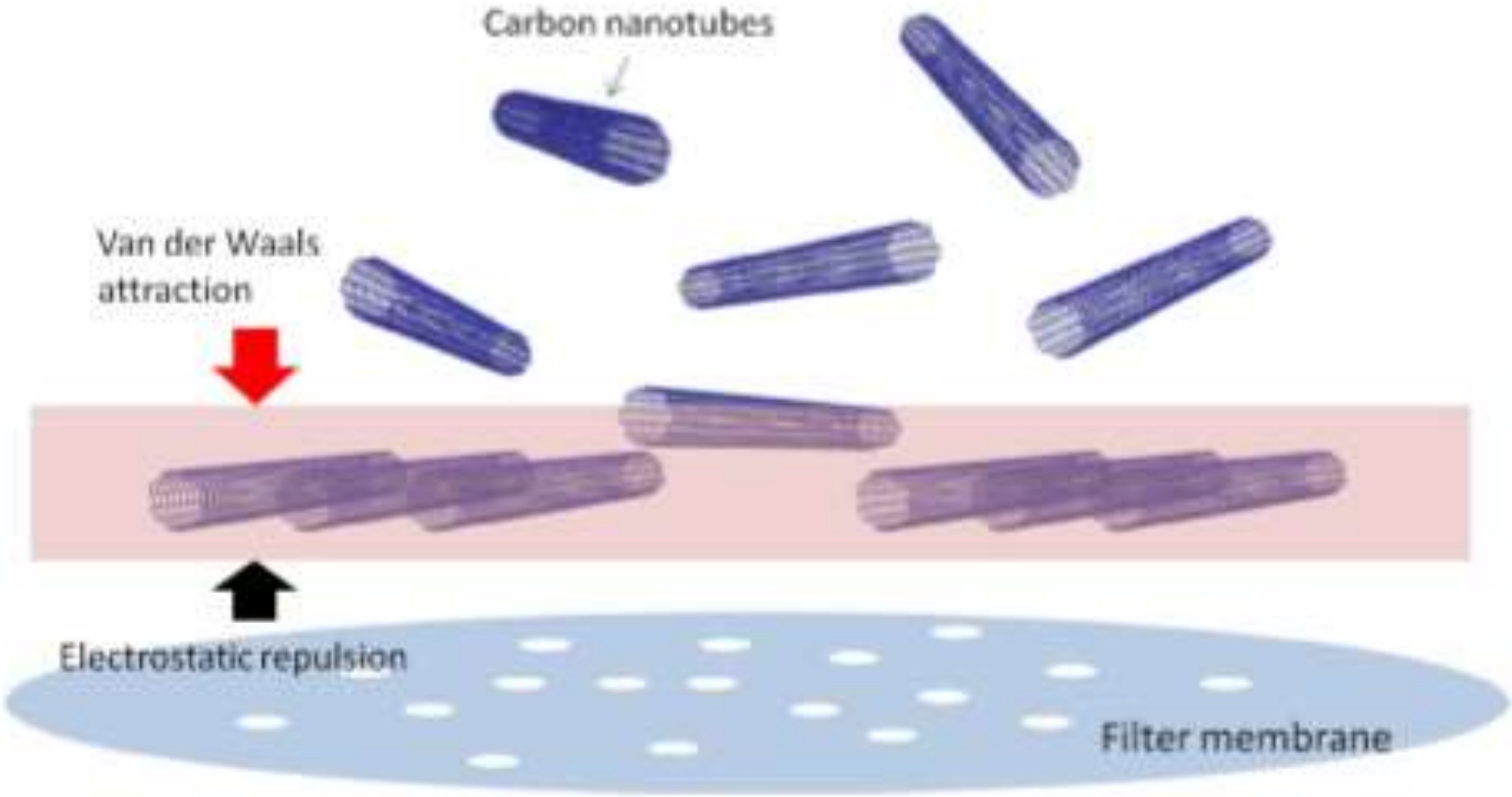
- According to Onsager, for anisotropic rigid rods the nematic order should have a maximum of 0.79[3,4]
- Linear Dichroism is defined as $LD = (A_{\parallel} - A_{\perp})$
- Defined as $LD^r = \frac{LD}{A_0} = \frac{3LD}{(A_{\parallel}+2A_{\perp})} = \frac{3(A_{\parallel}-A_{\perp})}{(A_{\parallel}+2A_{\perp})}$
  - Normalized by A_0, the absorption of unaligned SWCNT[2]
- Used to approximate the nematic order of SWCNT
- $LD^r = 0.28\ and\ 0.22$ at different locations on the film

Band diagram description of $A_{\parallel}$ and $A_{\perp}$ optical transitions of parallel and perpendicular. Not to scale.



[2] Searles, Thomas, *et al.*, Pysical Review Letters. DOI:10.1103/PhysRevLett.105.017403
[3] Puech, Nicolas, *et. al., J. Phys. Chem.* dx.doi.org/10.1021/jp1102077
[4] Onsager, Lars. *The effects of shape on the interaction of colloidal particles.* Ann. NY Academy of Science. 51, 627-659 (1949)

Proposed Mechanism of Alignment



Depiction of forces involved in alignment [1]

[1] He, Xiaowei, *et al.*, Nature Nanotechnology. DOI:10.1038/NNANO.2016.44.

Summary

- Successful characterization of SWCNT films
- Demonstration of alignment through two techniques
- Ability to measure Reduced Linear Dichroism

Future plans

- Further work with polarized optical absorption and polarized optical microscopy with metallic nanotubes
- Polarized Raman spectroscopy
- Using photoluminescence excitation spectroscopy to further investigate the alignment of the semiconducting SWCNT
- Electrical conductivity measurements of aligned SWCNT thin films

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