Mechanical Engineering and Materials Science Department, Swanson School of Engineering

Pulse Laser Induced Nanoparticle Formation on Stainless Steel for Carbon Nanotube Growth

Aiden Zurcher

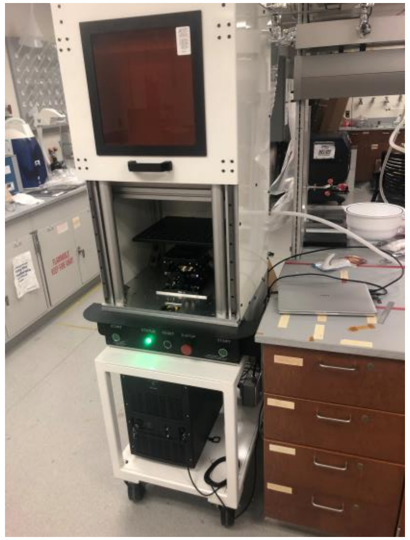
April 17, 2026

Objective:

Decoupling the Effect of Frequency and Scanning Speed

Project Resources

- Nanoproduct Lab
  - *Vulcan* Rapid Thermal Chemical Vapor Deposition (RT-CVD) reactor
  - MD-T Series Telecentric Q-Switch Green Pulsed Laser
- Advised by Dr. Mostafa Bedewy
  - With help from Diala Mustafa, Zhenhao Wu, Mirza Sahaluddin and Fahim Shahriar
- Nanoscale Fabrication and Characterization Facility
  - Optical and Scanning Electron Microscope



University of Pittsburgh

Carbon Nanotubes (CNT)

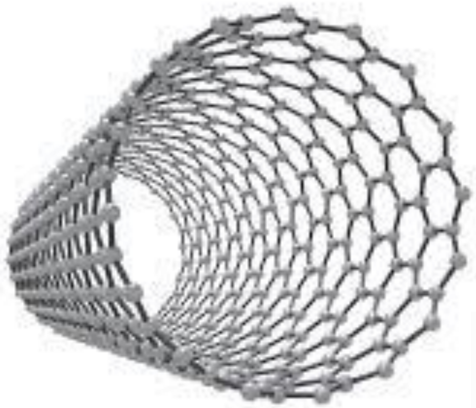
- High compression strength
- Ballistic conduction
- Super hydrophobicity
- Light weight and high aspect ratio
- Many applications
  - Sensors, electrodes, solar cells

Stainless Steel (SS)

- Widely used
- High durability and strength
- Corrosion resistance
- Recyclable
- Many applications
  - Medical, construction, automotive

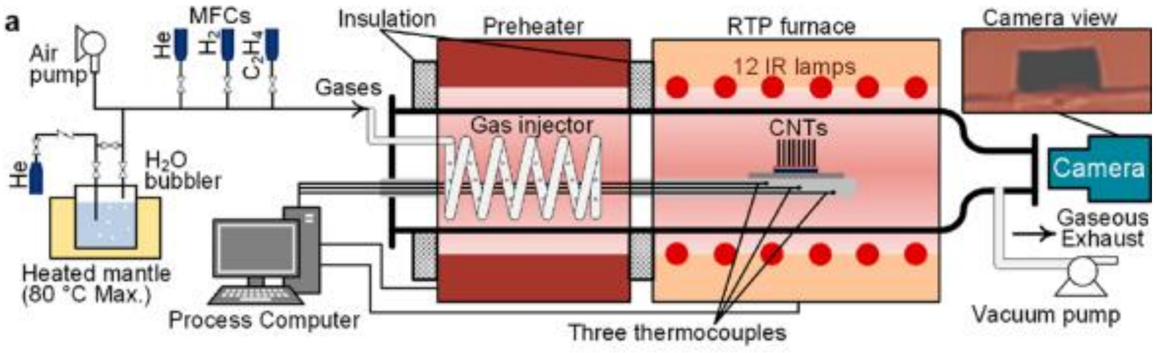
Leading to many benefits…

- Leverage CNTs advantages
- Enhanced Heat Transfer
- Anti-Fouling or Anti-Microbial Coatings
- Improving Electrodes



Current Methodology - Chemical Vapor Deposition

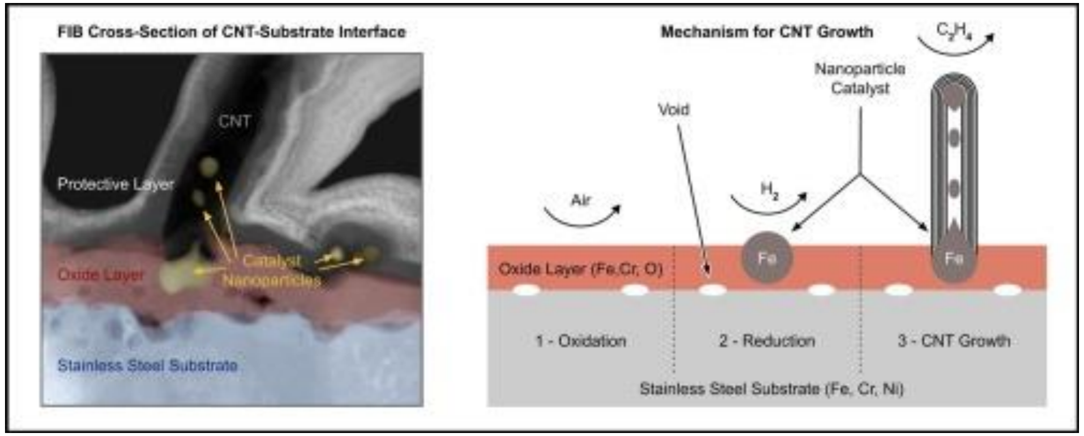
- Most widely used due to scalability
- Crack hydro-carbon gas at surface region
- Carbon supersaturates surface
- Precipitation grows CNTs
- Requires nanoparticle catalyst



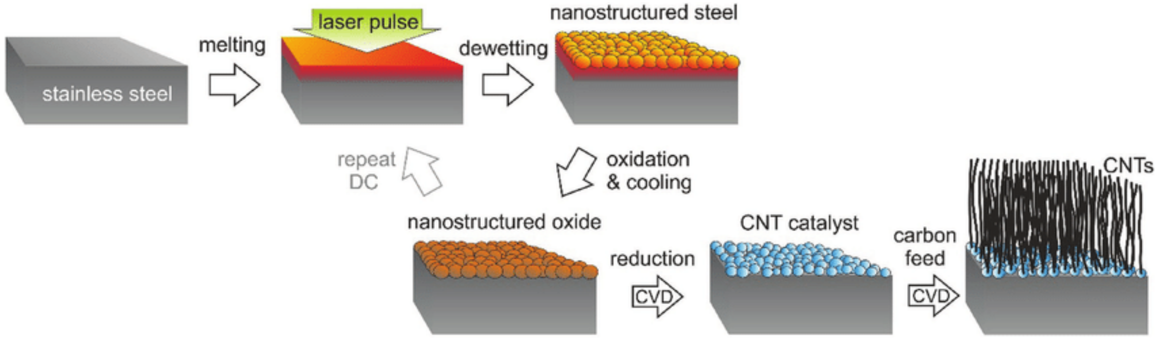
Lee, J.; Abdulhafez, M.; Bedewy, M. Decoupling Catalyst Dewetting, Gas Decomposition, and Surface Reactions in Carbon Nanotube Forest Growth Reveals Dependence of Density on Nucleation Temperature. *The Journal of Physical Chemistry C* **2019**, *123* (47), 28726–28738. https://doi.org/10.1021/acs.jpcc.9b07894.

How to prepare stainless steel?

- Iron, cobalt or nickel nanopartices
- Catalyst Nanoparticle Deposition
- Thermal Oxidation
- Newer method: pulsed laser induced nanoparticle formation



Hancock, J. D.; Michas, A. K.; Jensen, B. D.; Rivera, F.; Vanfleet, R. R. Mechanisms for Carbon Nanotube Growth on Oxidized 316L Stainless Steel Substrates. *Applied Surface Science* 2025, *710*, 163993. https://doi.org/10.1016/j.apsusc.2025.163993.

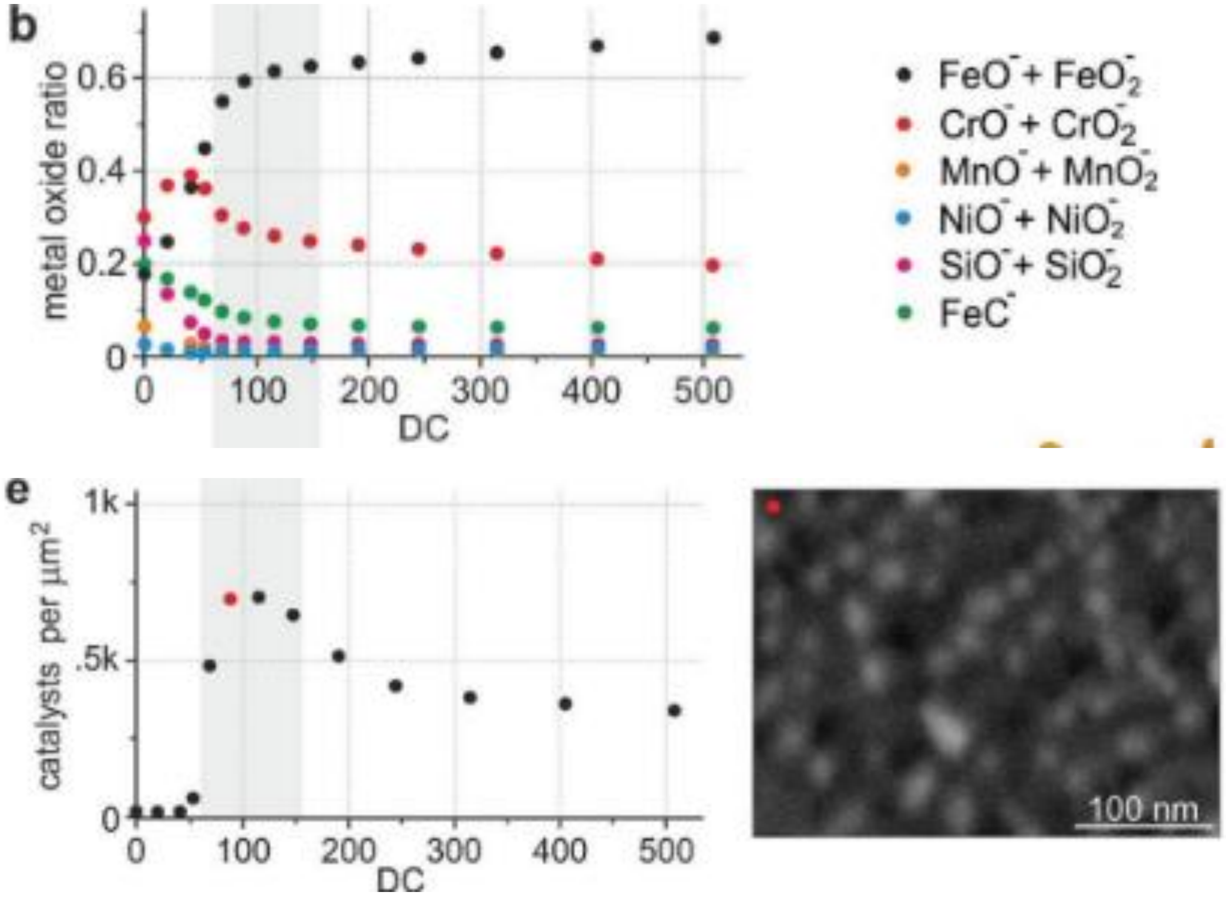


H.Reinhardt, C.Hellmann, P.Nürnberger, S.Kachel, N.Hampp, Adv. Mater. Interfaces 2017, 4, a. https://doi.org/10.1002/admi.201700508

University of Pittsburgh

Literature Review

- Examined by one group in Germany
- “Sweet spot” exists where CNT height is maximized
- Found a strong relationship between Dewetting Cycles and CNT structure



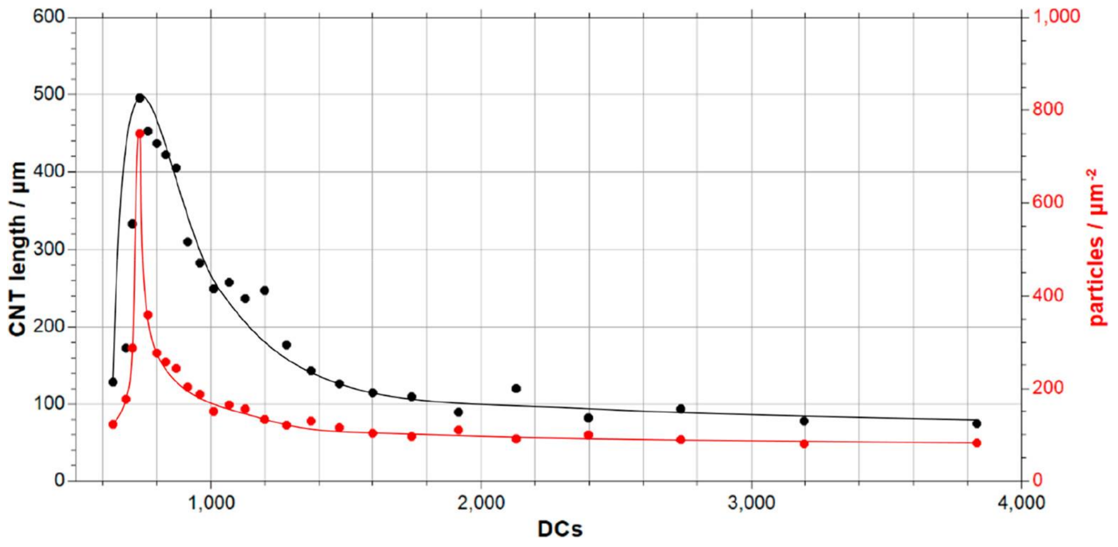
H.Reinhardt, C.Hellmann, P.Nürnberger, S.Kachel, N.Hampp, Adv. Mater. Interfaces2017, 4, 1700508. https://doi.org/10.1002/admi.201700508

Dewetting Cycles (DCs)

- Number of times a location is pulsed with the laser
  - Literature standard
- Conflates frequency and scanning speed.
  - Objective: decouple them

$$DC = \frac{d}{v}f$$

$$where\ d: laser\ diameter$$
$$v: scanning\ speed$$
$$f: frequency$$

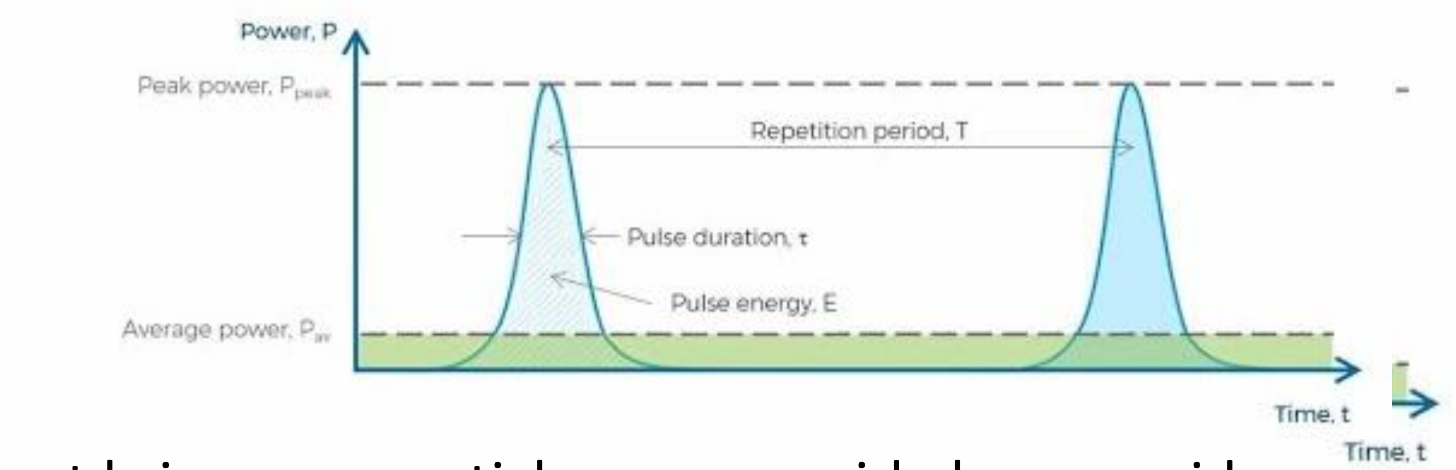


Dasbach, M.; Pyschik, M.; Lehmann, V.; Parey, K.; Rhinow, D.; Reinhardt, H. M.; Hampp, N. A. Assembling Carbon Nanotube Architectures. *ACS nano* **2020**, *14* (7), 8181–8190. https://doi.org/10.1021/acsnano.0c01606.

University of Pittsburgh

Hypothesis

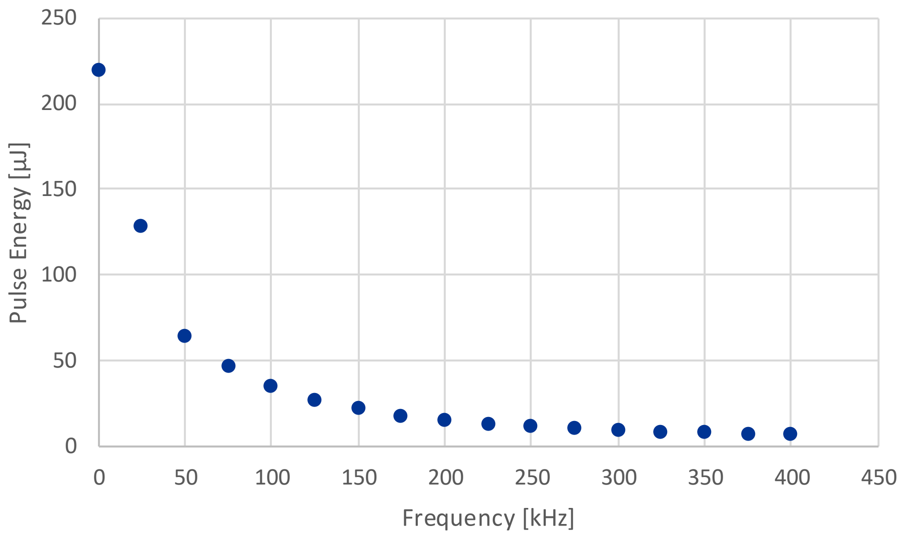
- Scanning Speed
  - Dominant effect on fluence
  - Deepens grooves and craters -> increase to cut
  - Increases feature density
- Frequency
  - Controls pulse energy
  - High heat accumulation
  - Strong effect on surface oxidation
  - Controls thermal regime

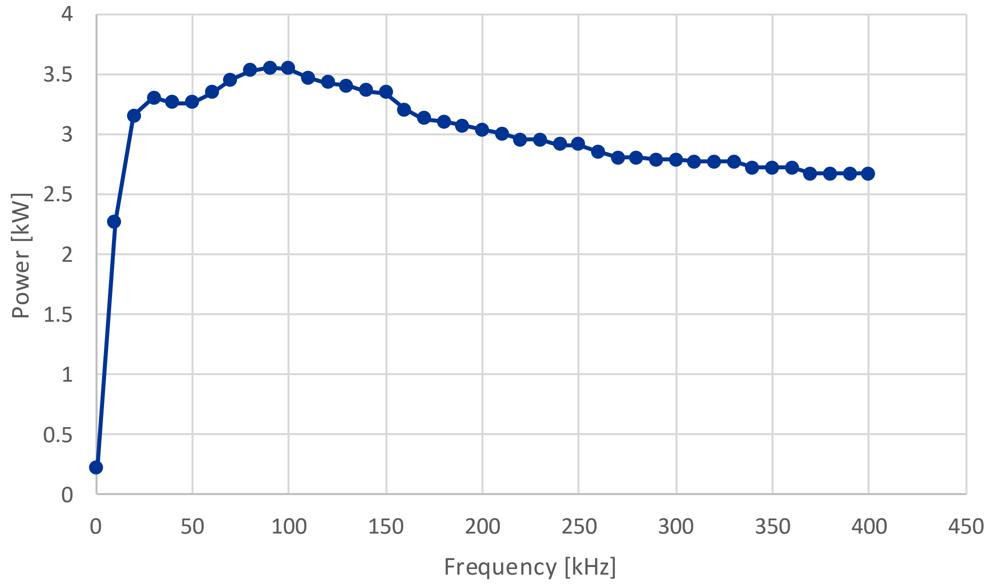


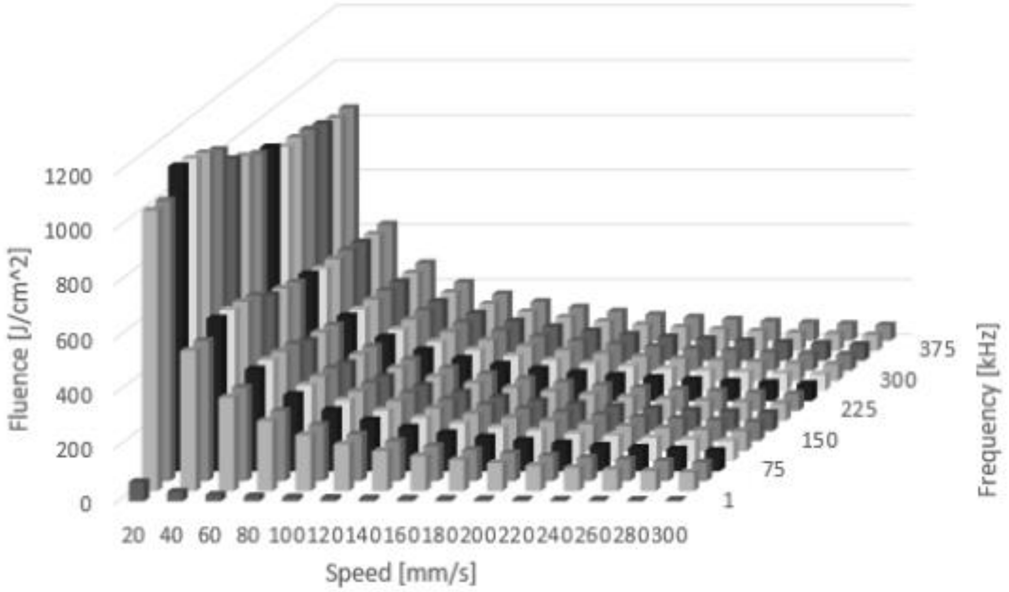
Fluence must bring nanoparticles across oxide layer – mid range

Laser Characterization

- Laser operates between 1 and 400 kHz
- Power output depends on frequency
- Low power caused by Q-switching



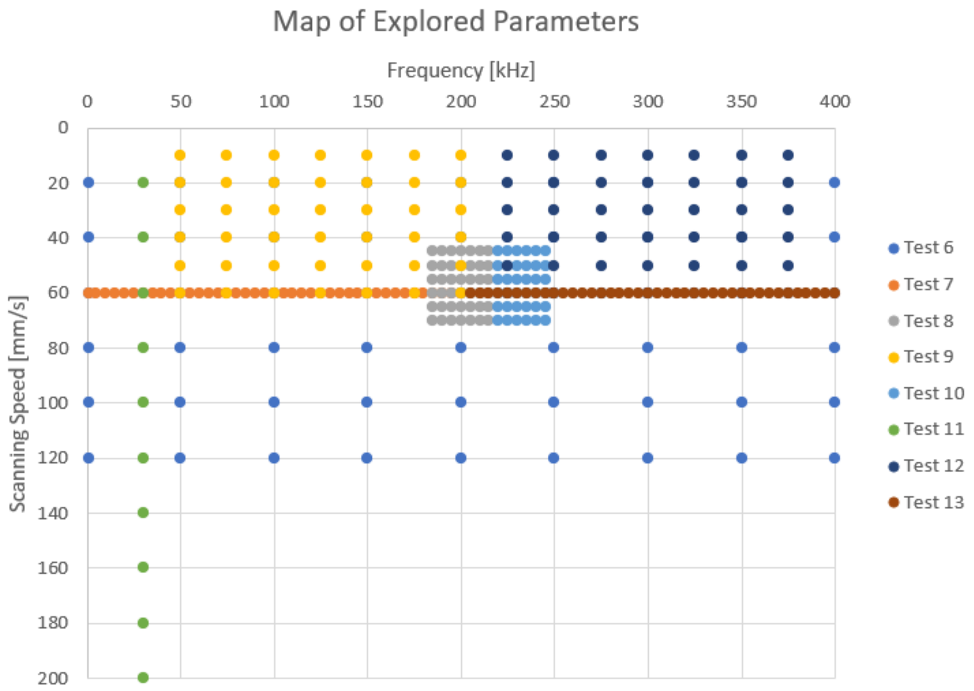


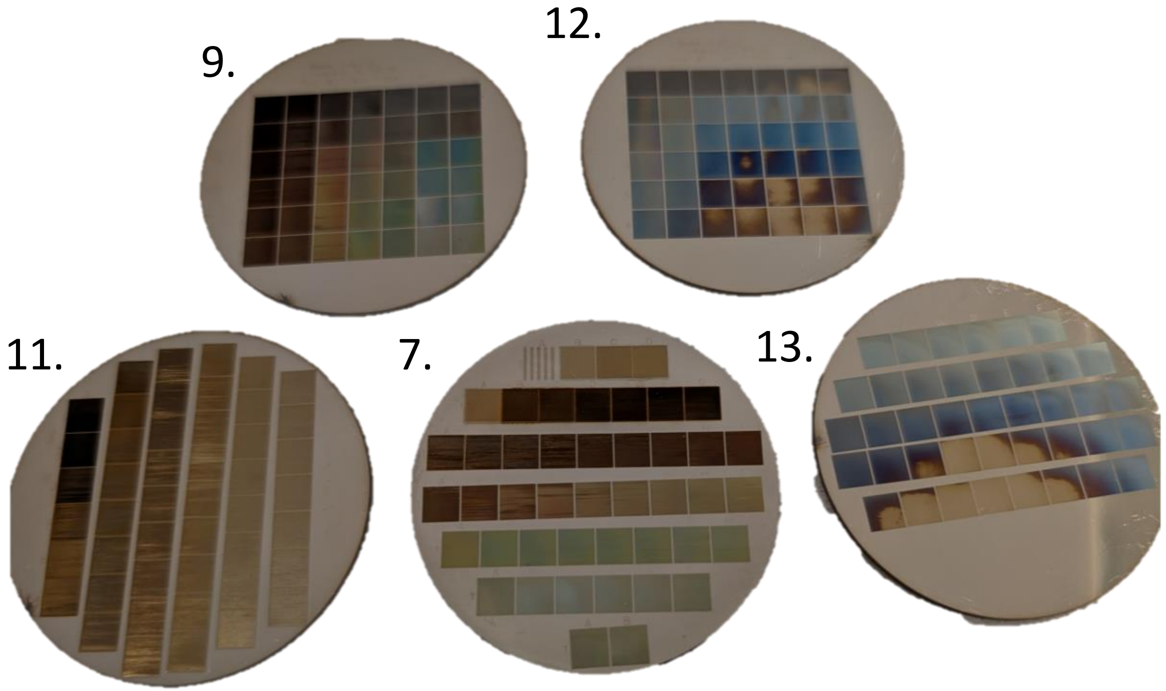


University of Pittsburgh

Stainless Steel Samples

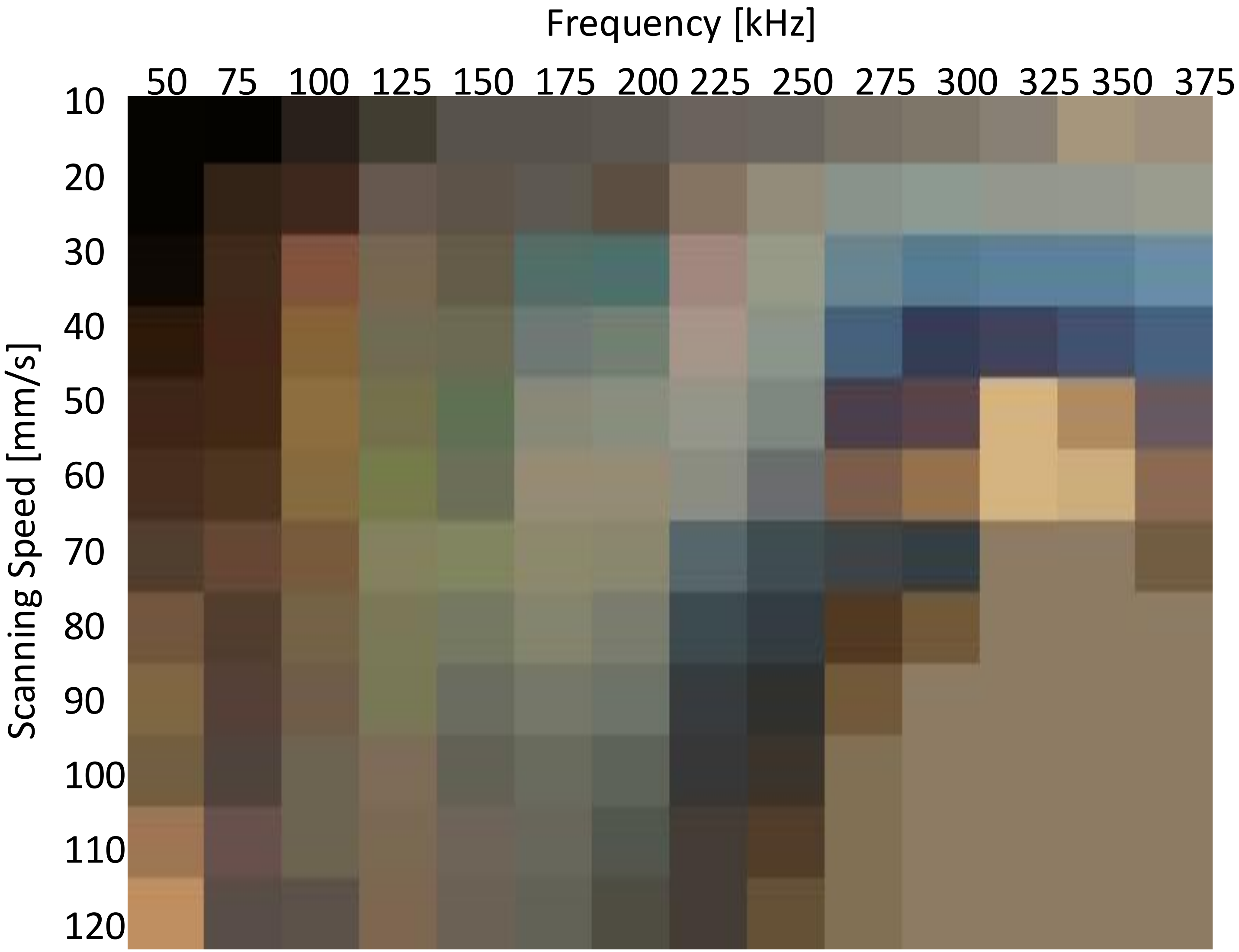
- Constants:
  - Hatch Distance, Power





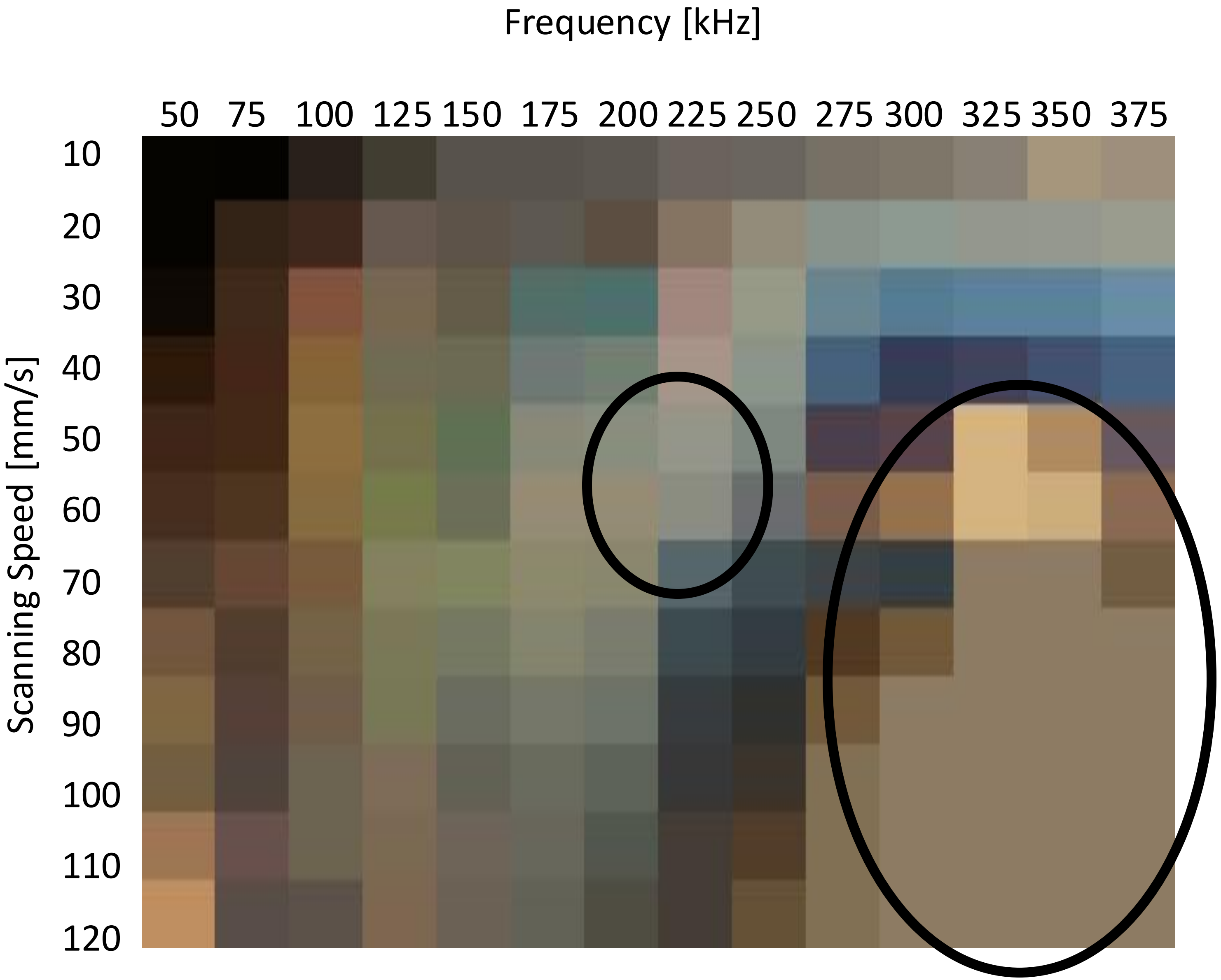
Coloration

- Scanning speed affects saturation
- Frequency affects hue
- Primarily determined by oxide layer thickness

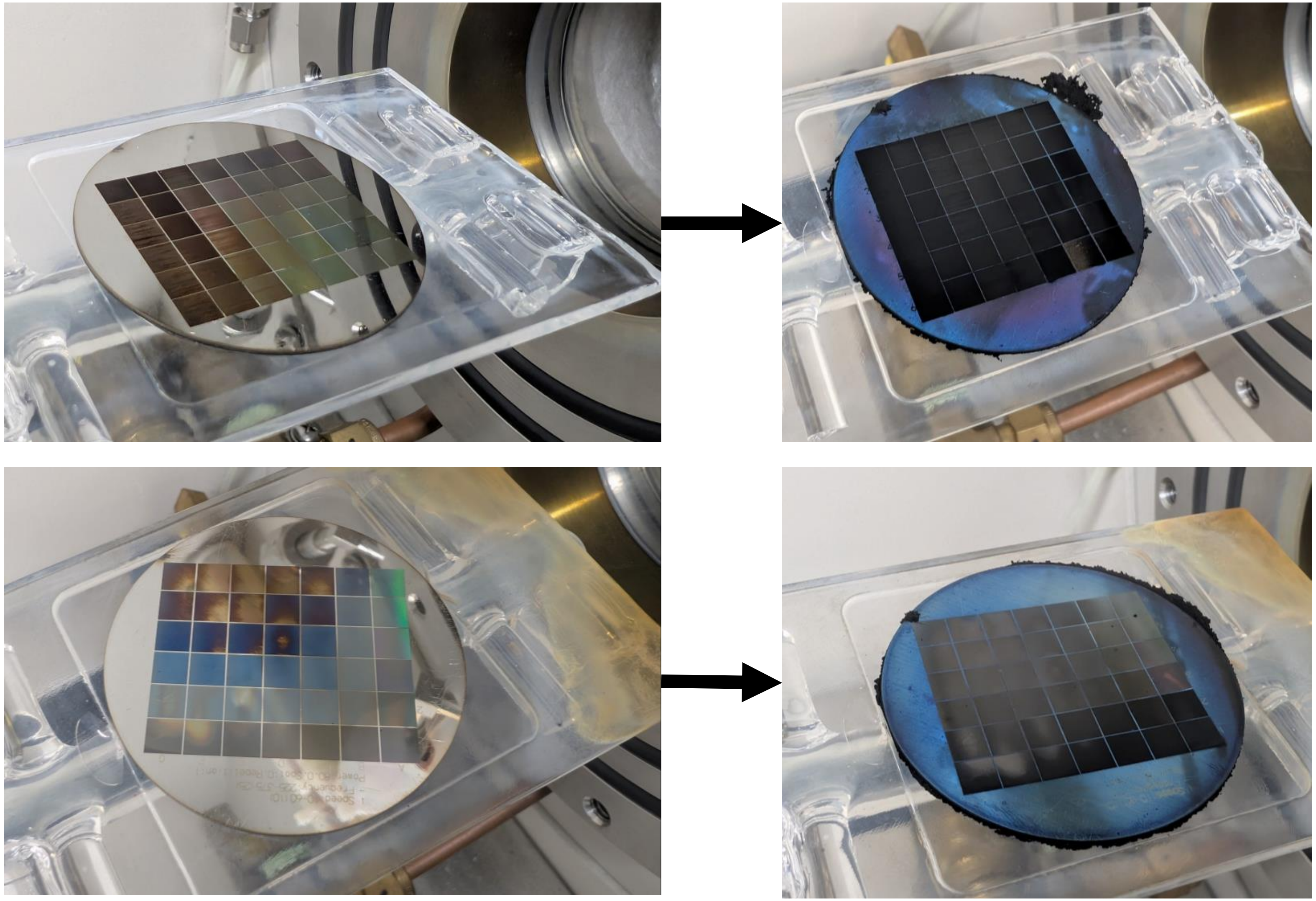


Notable areas

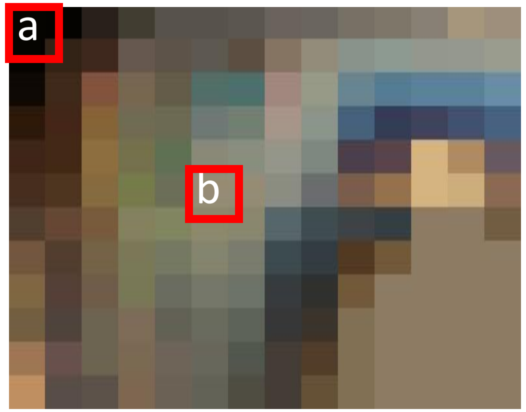
- Color becomes clear at high-frequency and scanning speed
- Iridescence occurs in mid ranges



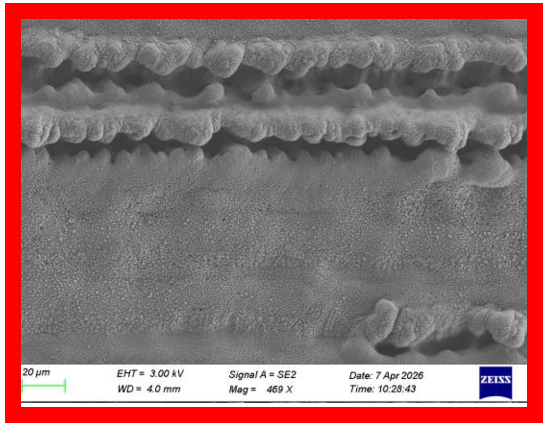
Carbon Nanotube Growth



Scanning Electron Microscopy



a

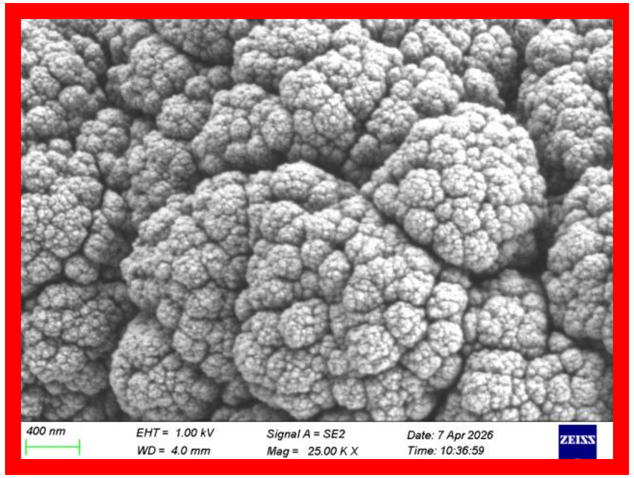


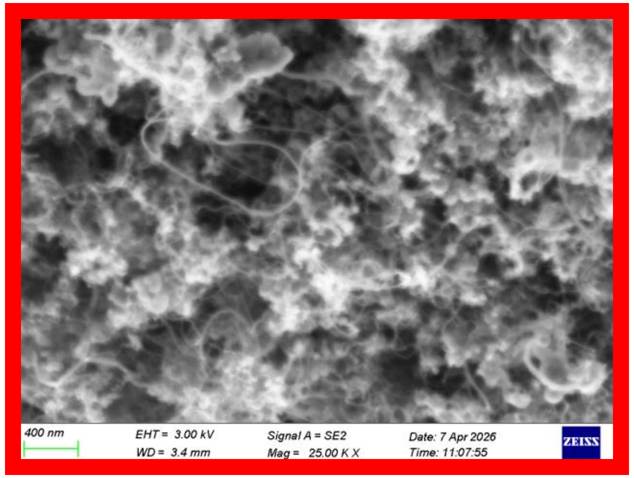
Lower magnification of a

Pre-CVD

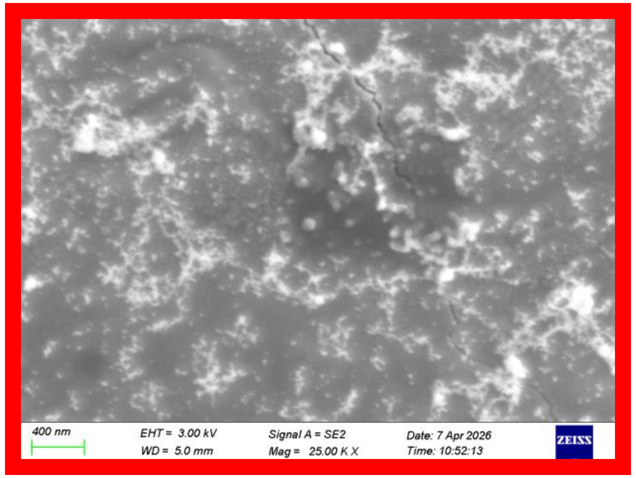
Post-CVD

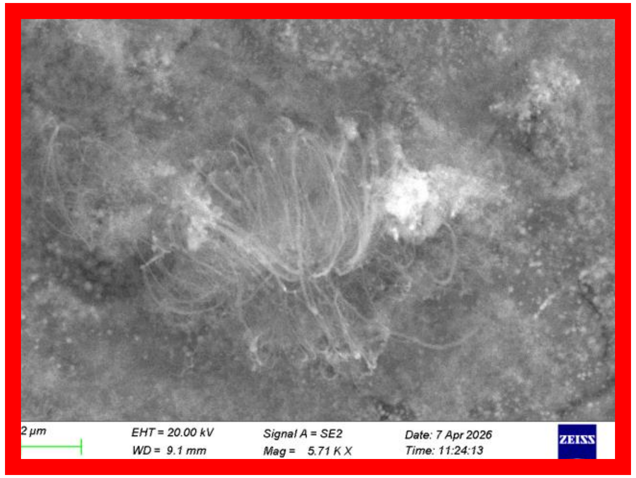
a





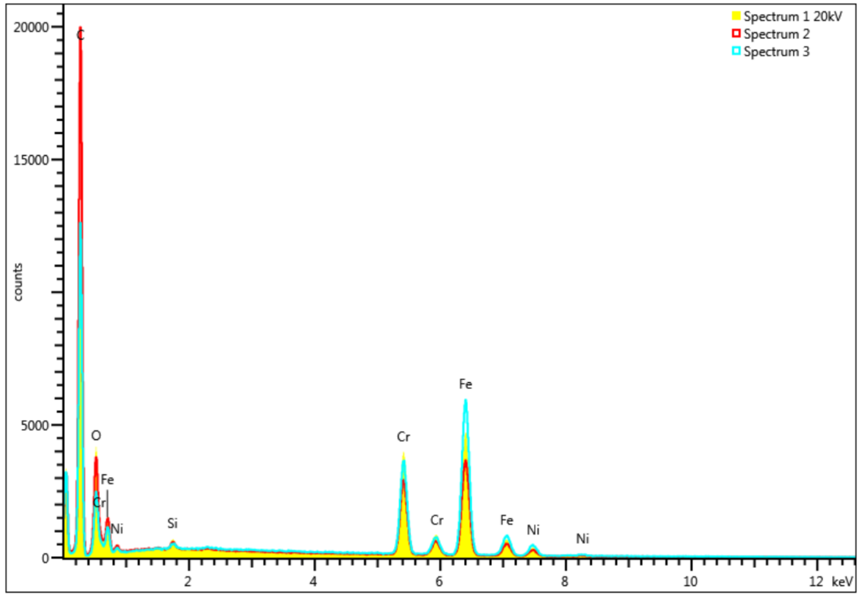
b

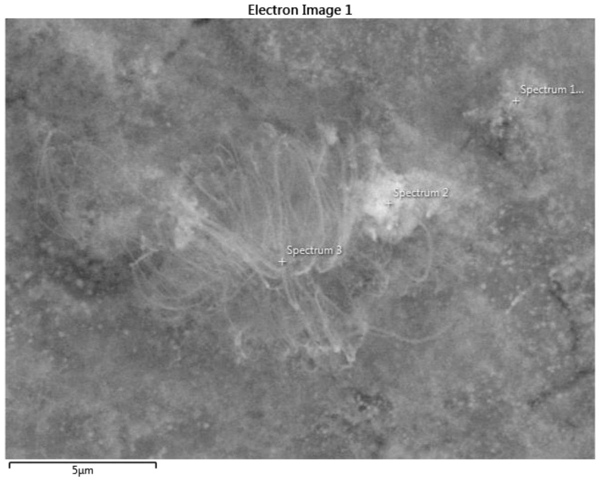


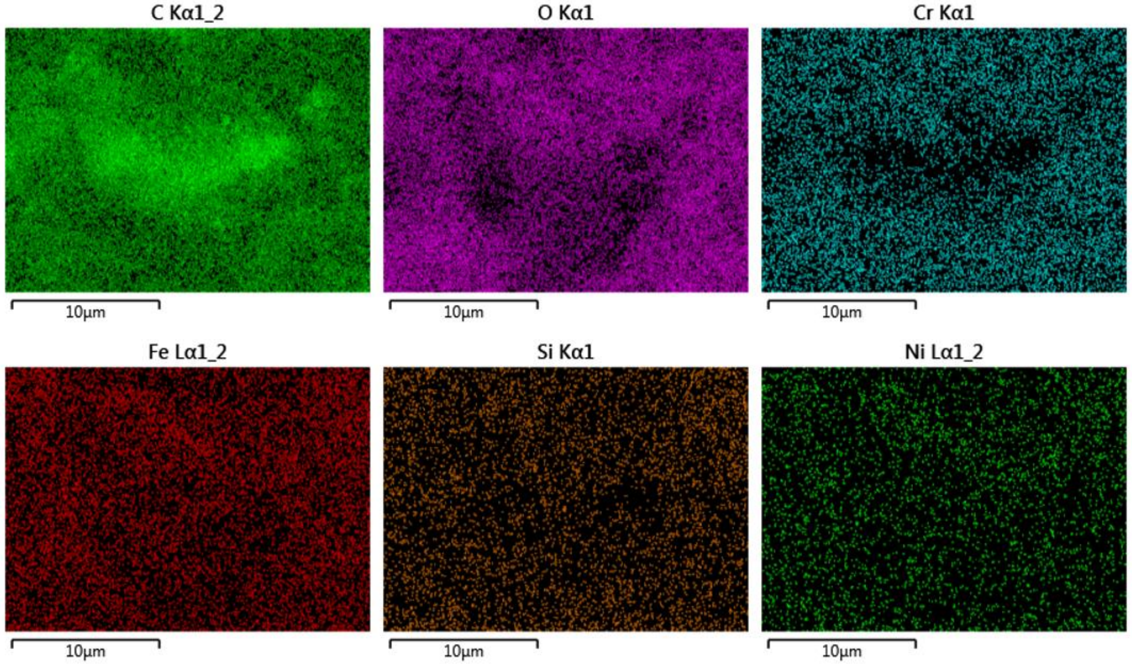


SEM - EDS

- C and Cr have inverse relationship
- Clear presence of nanotubes

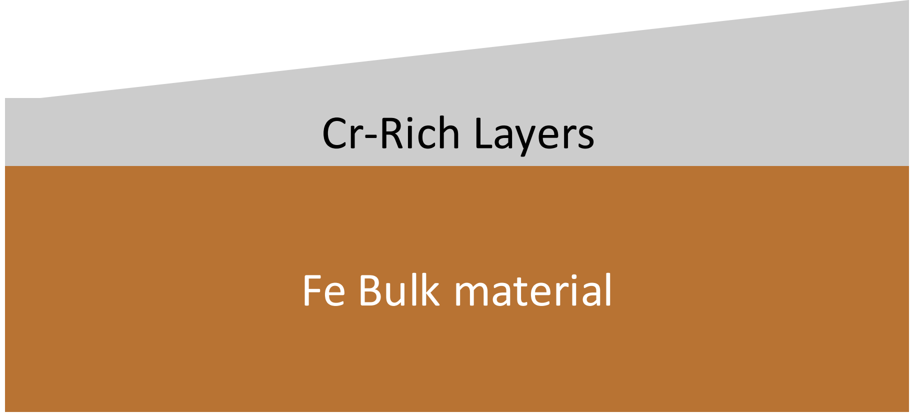


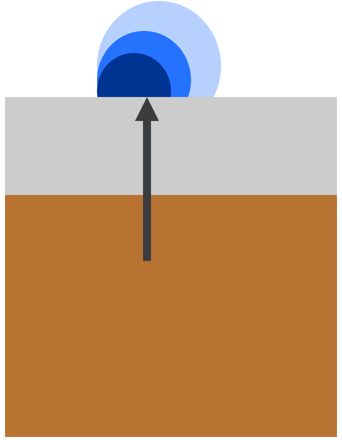




Discussion

- Oxide Layer Growth
- Nanoparticle formation
- Valley creation at high fluence
- Cr-layer maintains wetting of nanoparticle





University of Pittsburgh

Future Work

- Repeat the study with different analysis methods
- Explore parameter space
    - SEM, XRD on more parts of the surface.
    - Even higher and lower frequencies and scanning speed
- Improve sample standards for more regular carbon nanotubes
- Determine definitively whether dewetting occurs

University of Pittsburgh

Conclusion

- Frequency and Scanning Speed have different effects
  - Frequency has strong control over oxide layer
  - Scanning speed affects surface structure
- Quality of nanotubes can be predicted by color
  - Ideal nanoparticle formation occurs in blue and green regions
- The process can be modelled as a combination of oxide layer and nanoparticle formation

Parameters

- Q-Switch Pulse 532 wavelength laser
- 3 micrometer hatching
- 30 micrometer laser diameter
- 304 Stainless Steel
- CVD recipe: 750 for 10 minutes, with ethylene precursor