Towards nanoscale parallelism in VACNTs

From scratch

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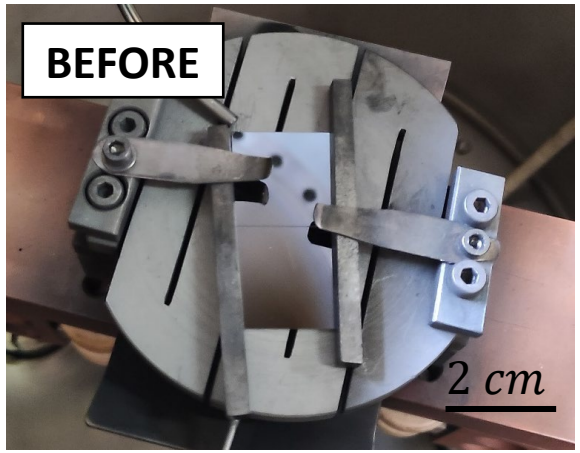
Ptolemy Italia Meeting

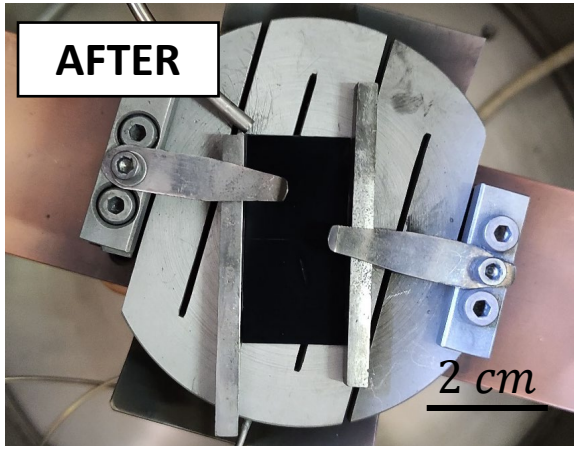
February 19th, 2025

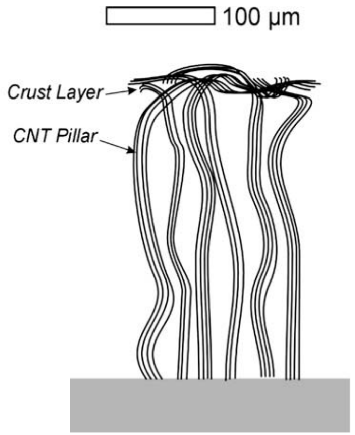
Summary

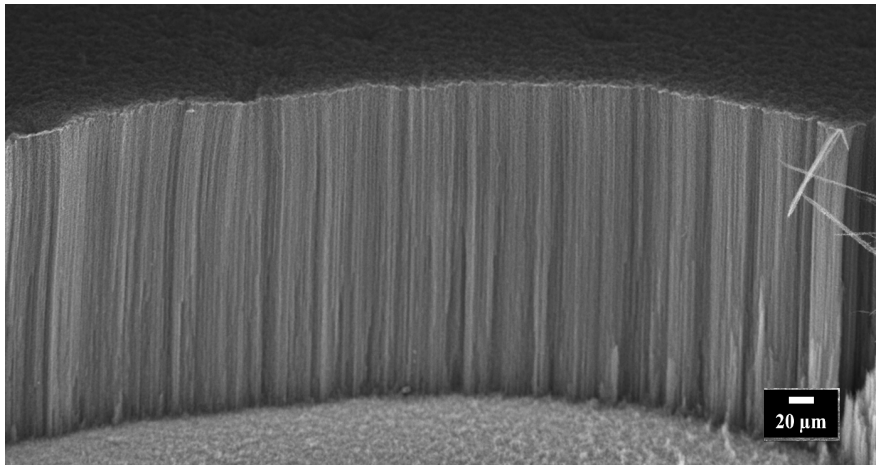
- Vertically Aligned Carbon Nanotubes (VACNTs)
- Why and How to reach parallelism @ nanoscale
- 1° solution: Plasma Enhanced CVD
- 2° solution: Optimization of nucleation sites
- Further optimizations & conclusions

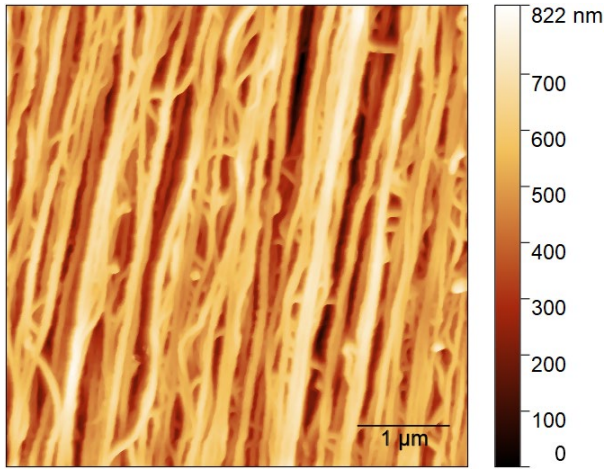
Vertically Aligned Carbon Nanotubes

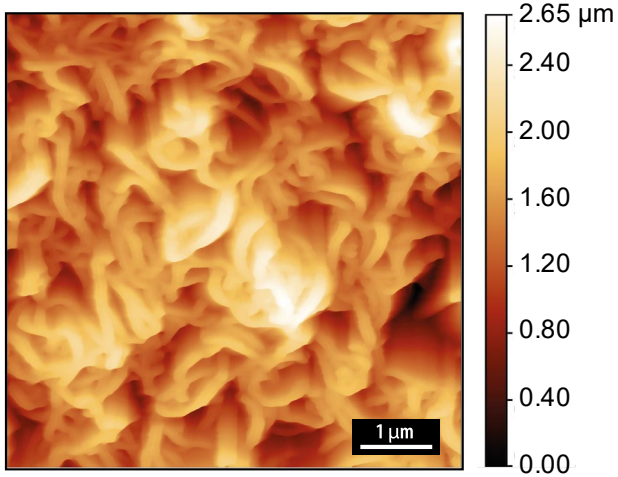




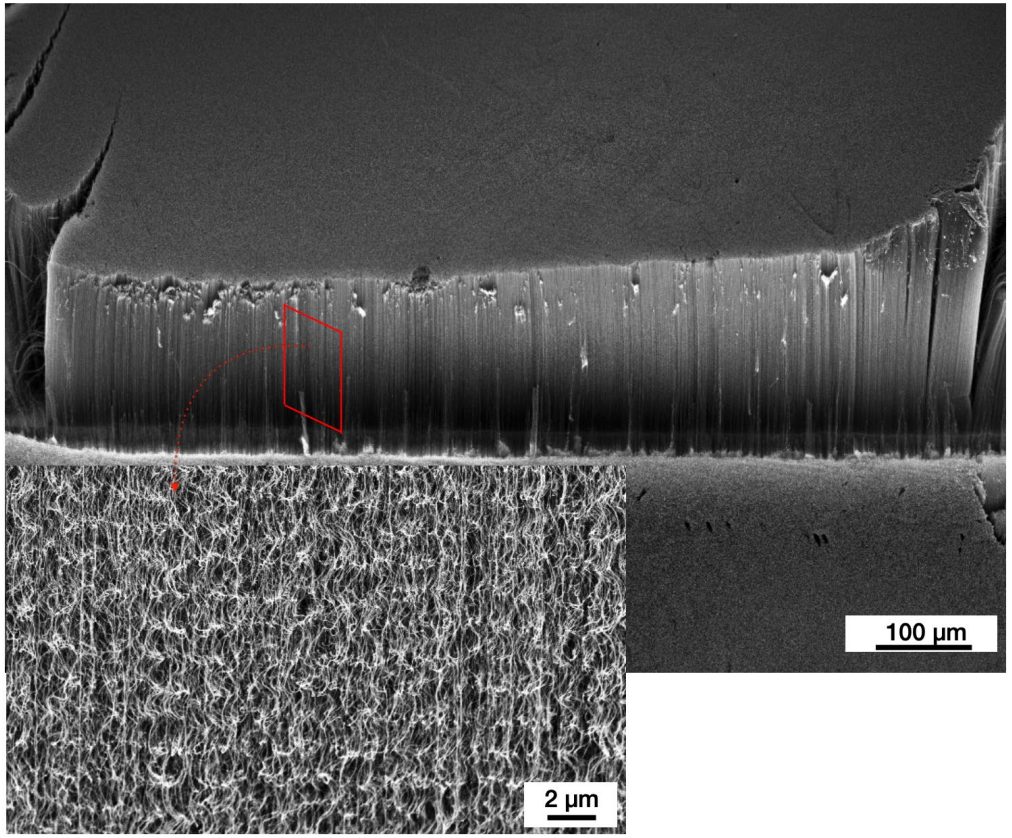




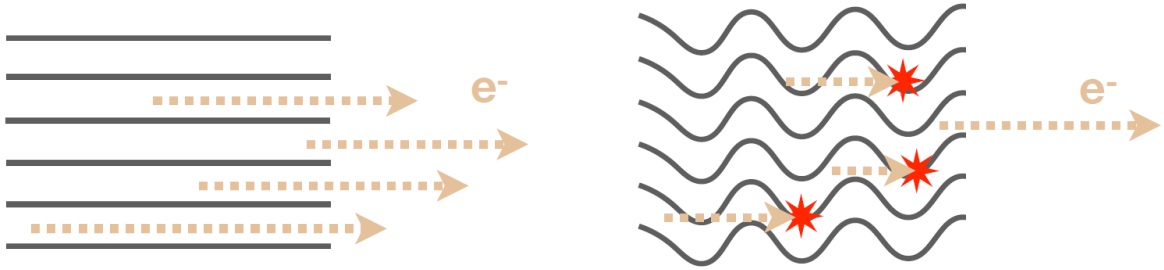




Parallelism @ nanoscale

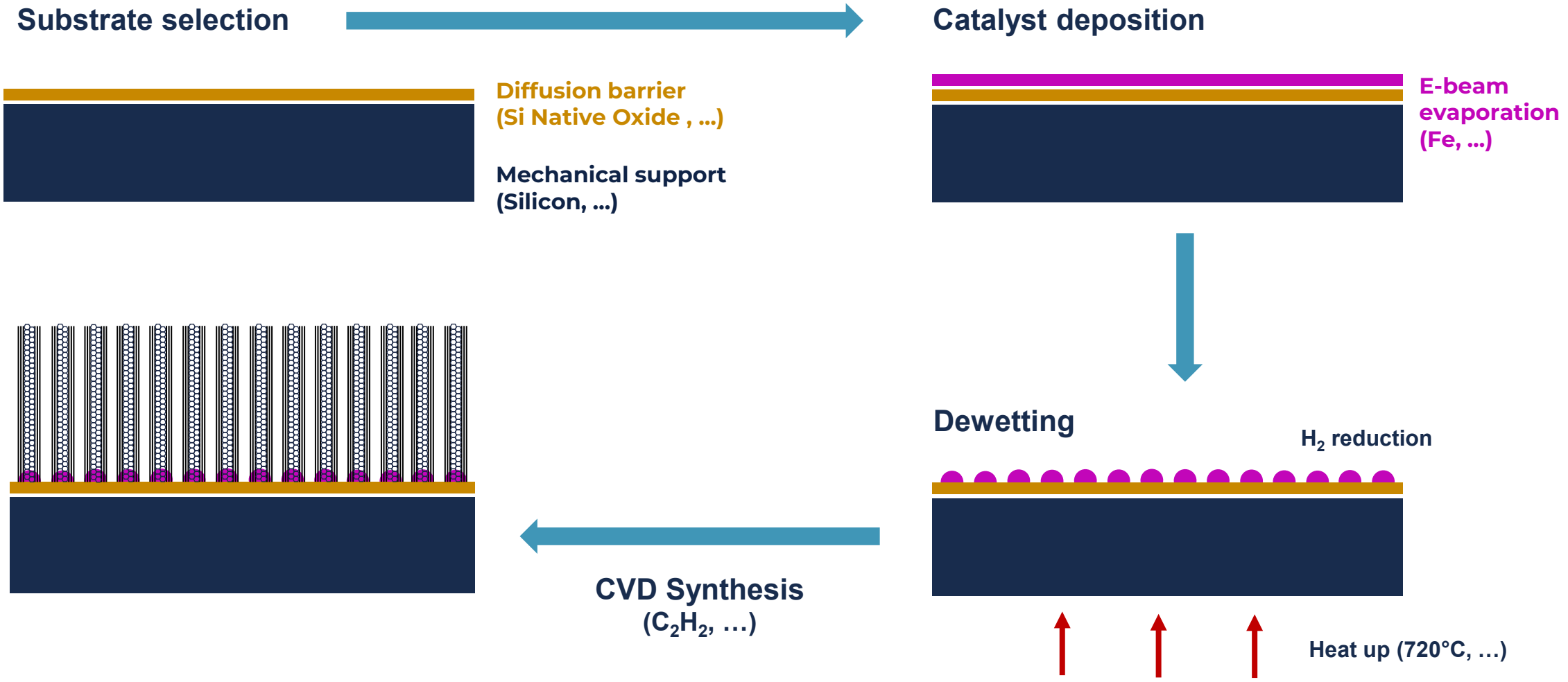


❖ Aligned parallely at microscale, local waviness at nanoscale.

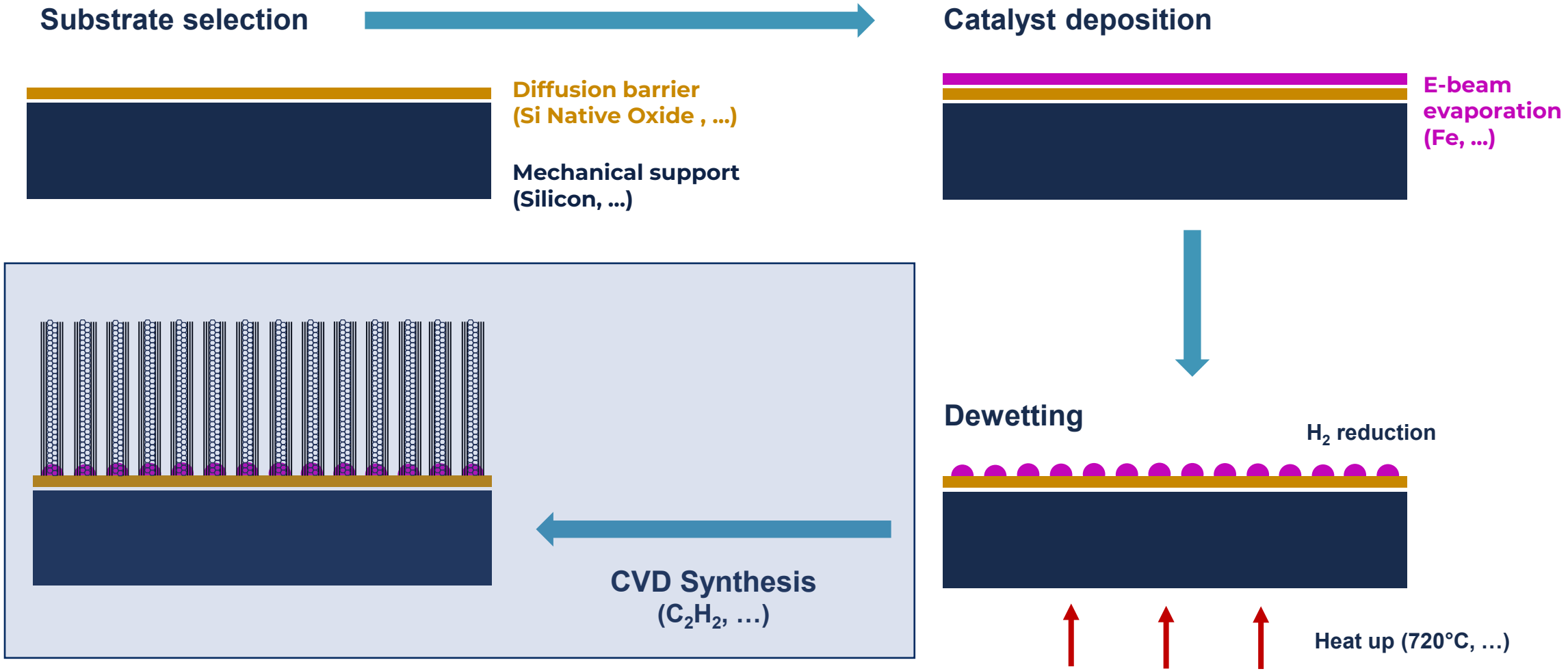


- Increase electron transmittance: towards channeling.
- Increase directional sensitivity of anisotropic detector

Nonlithographic synthesis of VACNTs



1st solution: PECVD

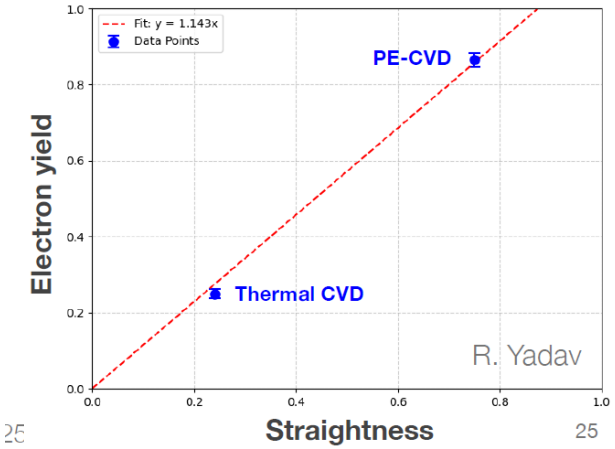


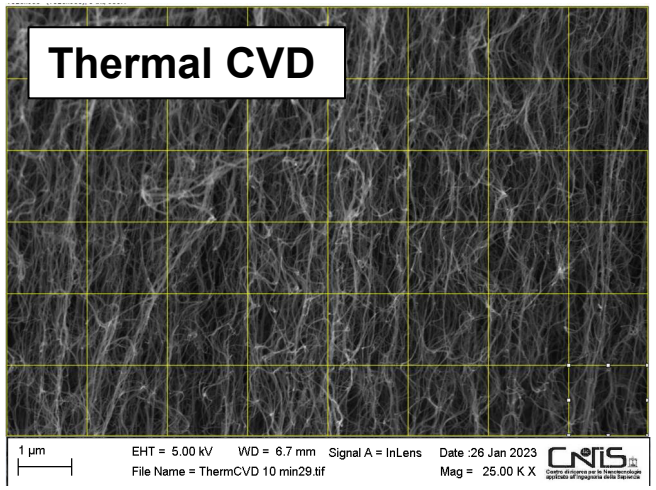
1st solution: PECVD

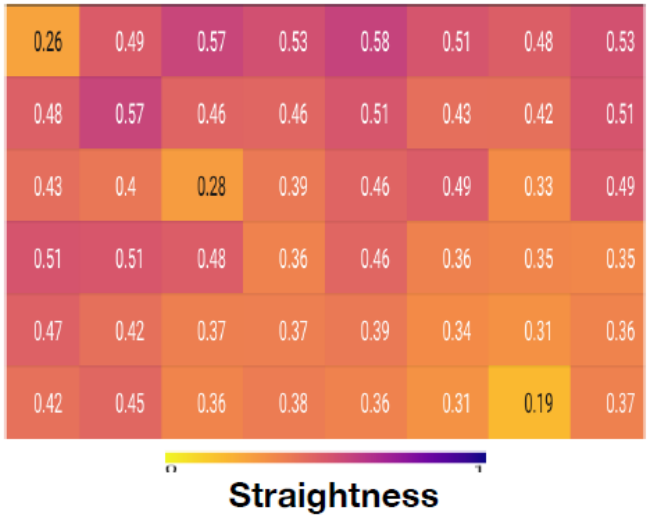
- RF Acetylene Plasma
- Quantitative analysis on morphology: straighness defined from image gradient

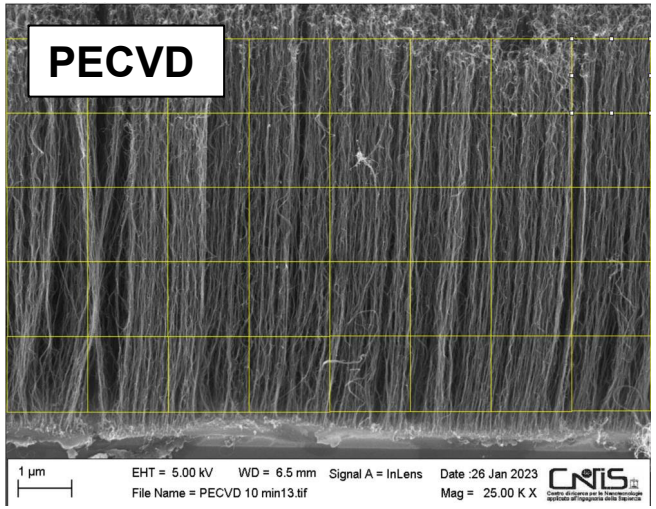
R. Yadav et al., *Evaluation of vertical alignment in carbon nanotubes: A quantitative approach*, 2024, https://doi.org/10.1016/j.nima.2024.169081.

- Confirmed qualitatively also by photoemission

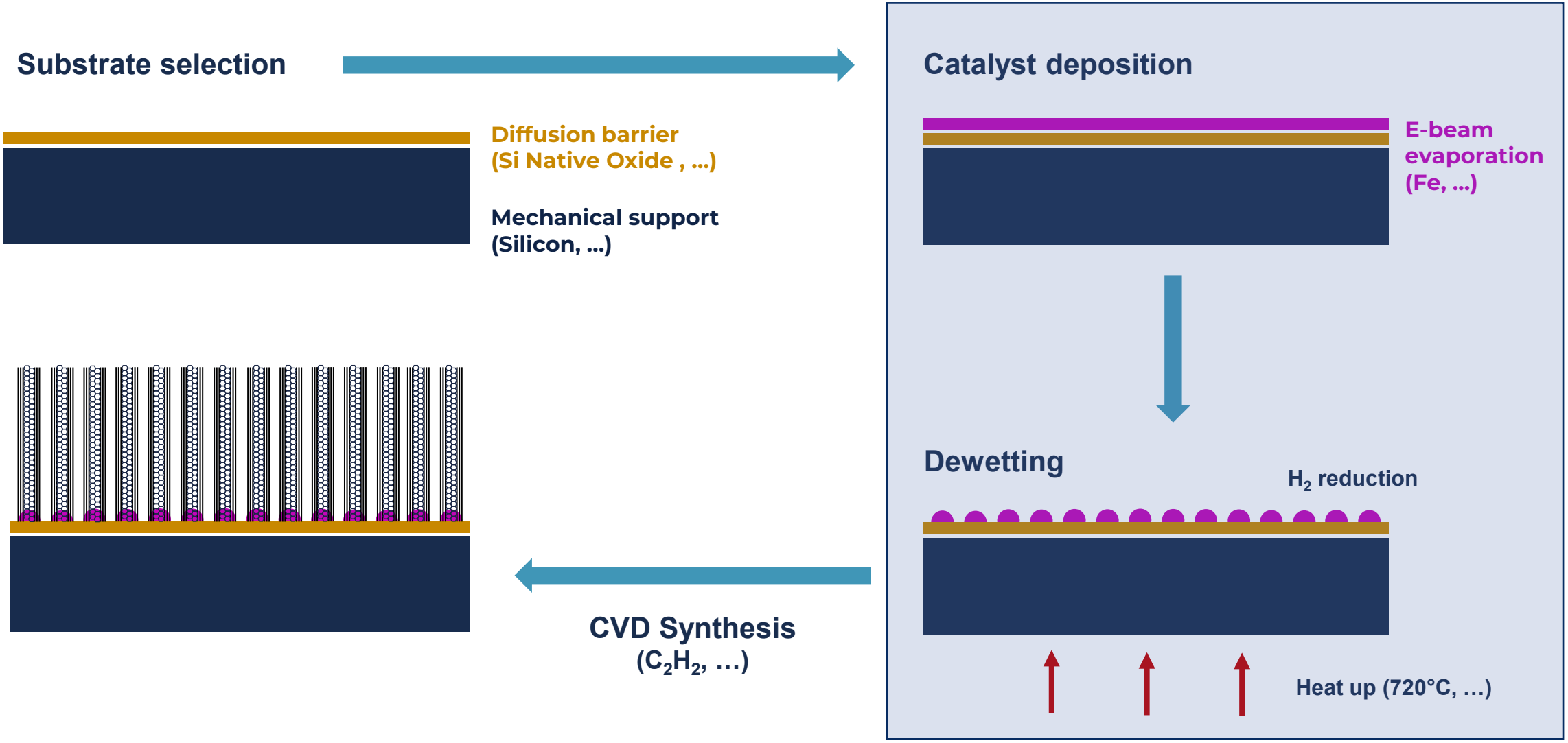








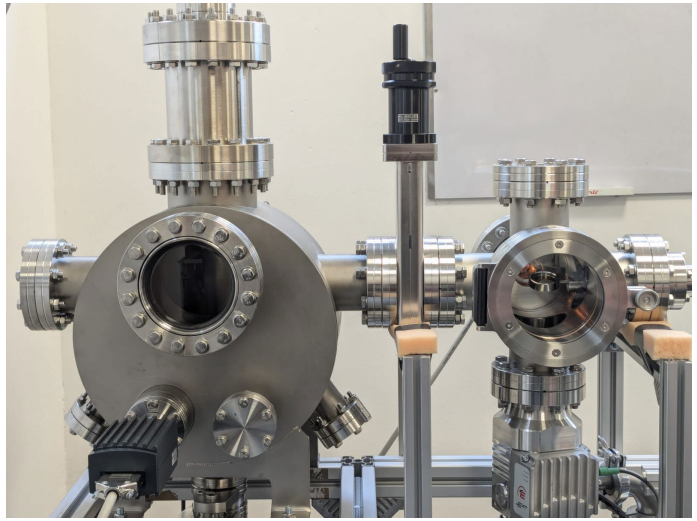
2nd solution: Nucleation sites



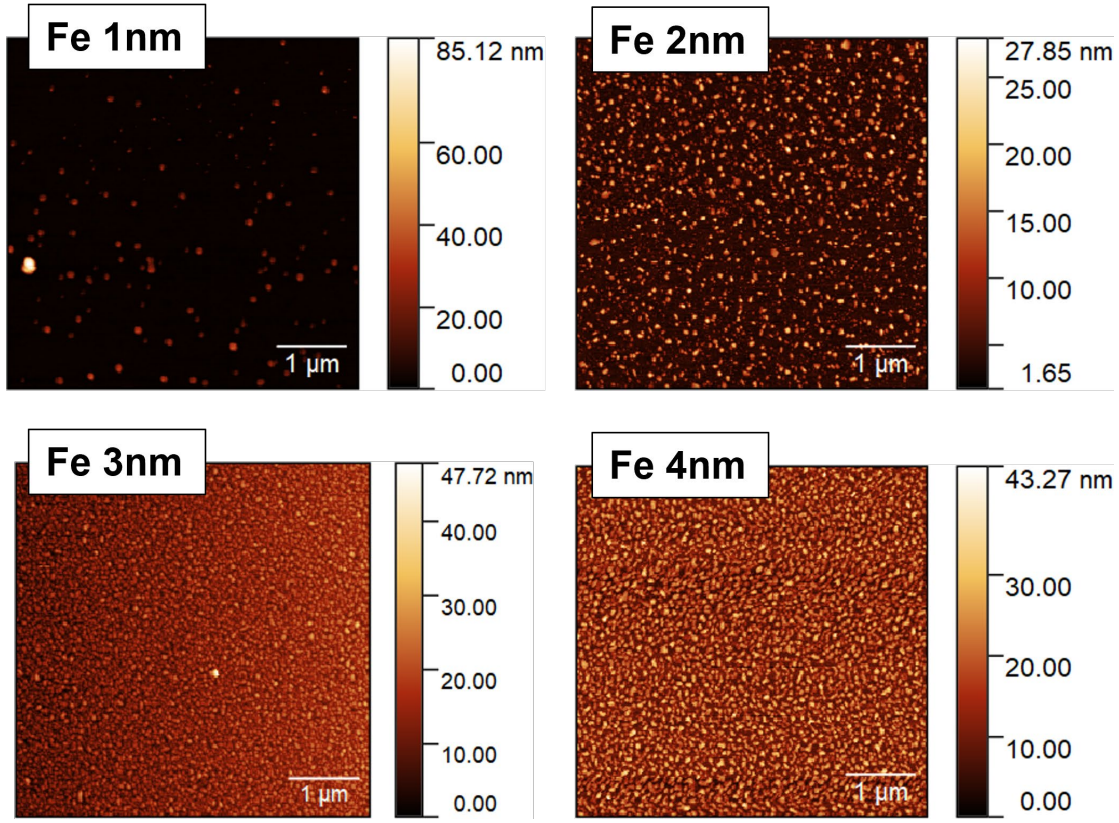
2nd solution: Nucleation sites

- More dense nanotubes means higher Van der Waals interactions: straighter!

New e-beam evaporator @Titan Lab

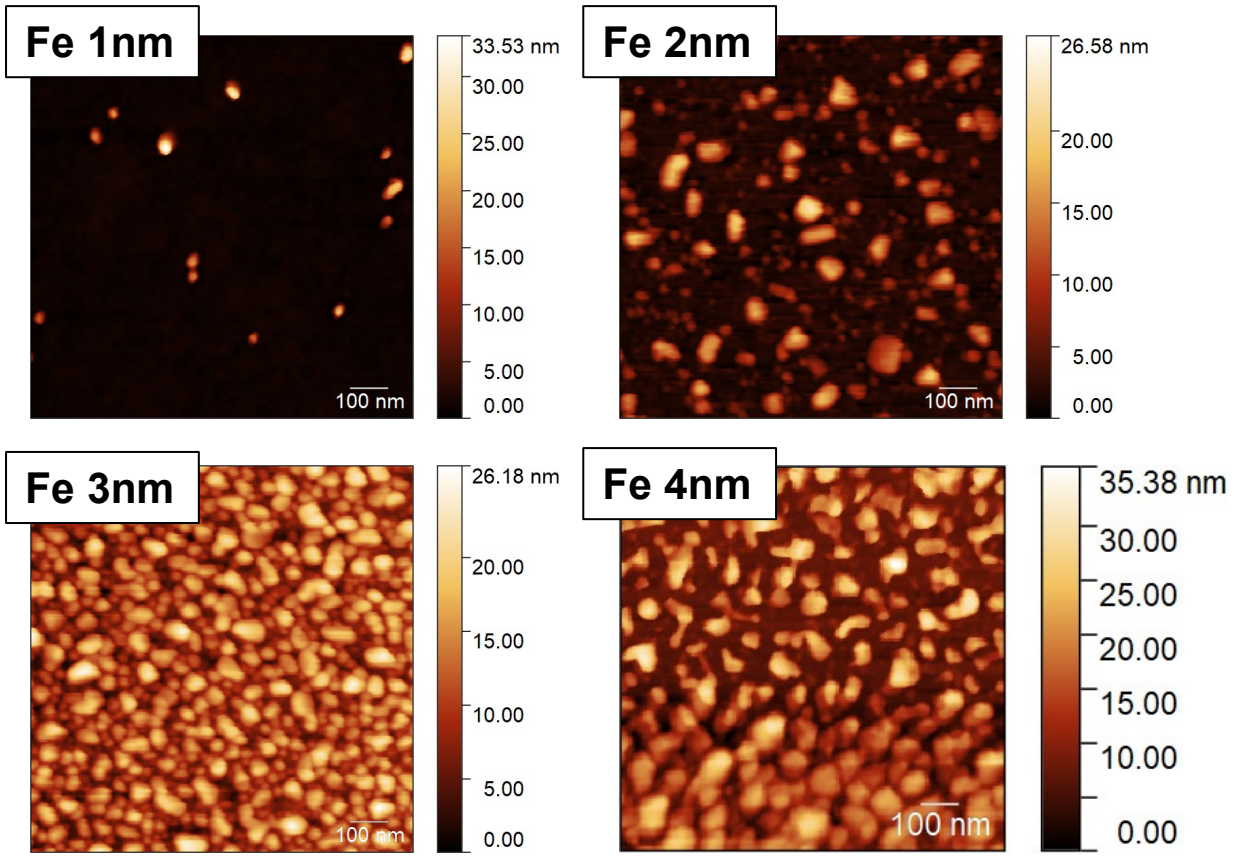


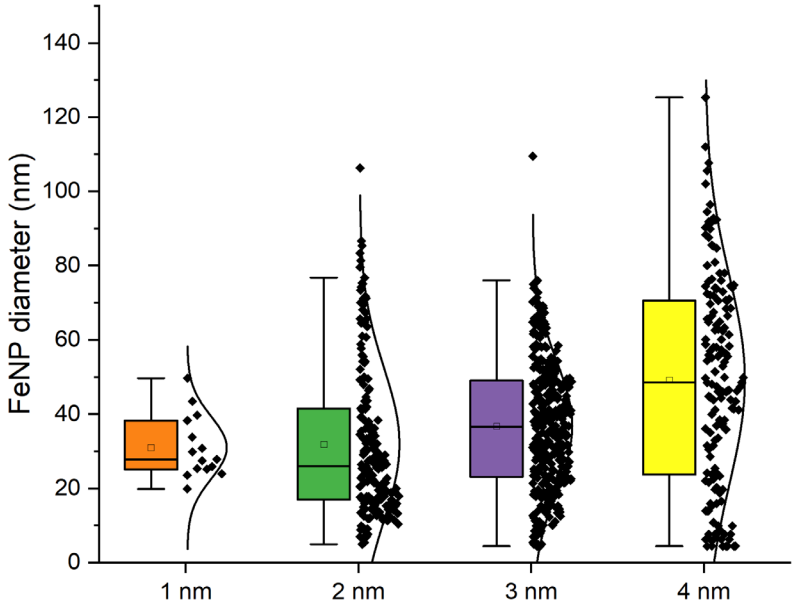
- Calibrated Fe deposition
- UHV: 10^{-9} mbar



- Optimize parameters to get density of FeNPs > 10^{12} cm^{-2}

2nd solution: An example





Fe Thickness (nm)	$\delta_{FeNP} \times 10^{10}$ cm^{-2}	Surface Coverage
1	0.21	1.2 %
2	1.98	21.9 %
3	3.38	44.1 %
4	1.54	38.7 %

Conclusions & Further optimization

- PECVD most suitable synthesis technique
- Increase density FeNPs (10^{12} cm^{-2} or more!) using commisioned E-beam evaporator
- Quantitative characterization of alignment (morphology, photoemission, …)
- Deposition of different diffusion layer (Al_2O_3,..)
- Use different substrate (Cu,…)
- H_2 plasma with FeNPs

Thanks for the attention.
Any question?

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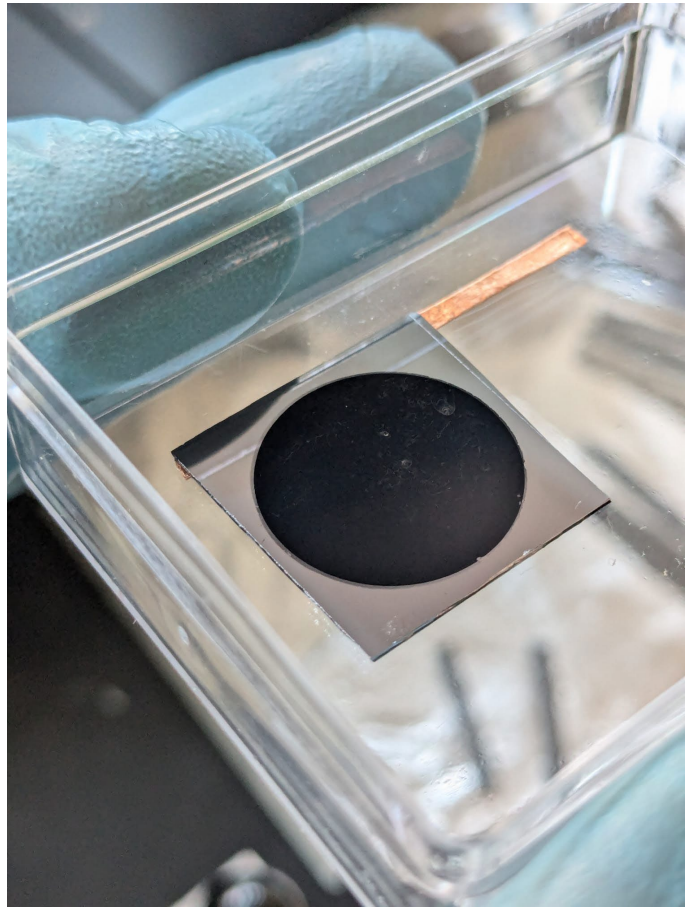
TitanLab: from Si to VACNTs

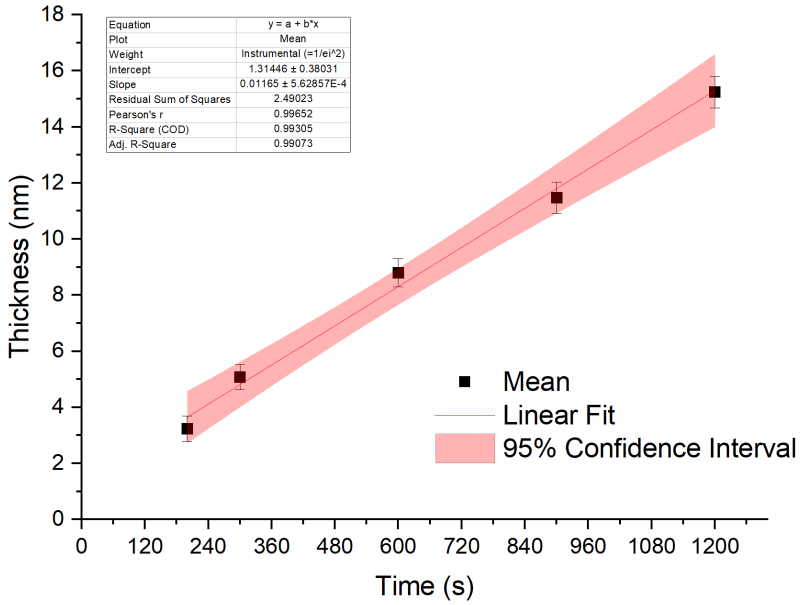
TITAN LAB

TECHNOLOGY INNOVATION THROUGH ADVANCED NANOSTRUCTURES



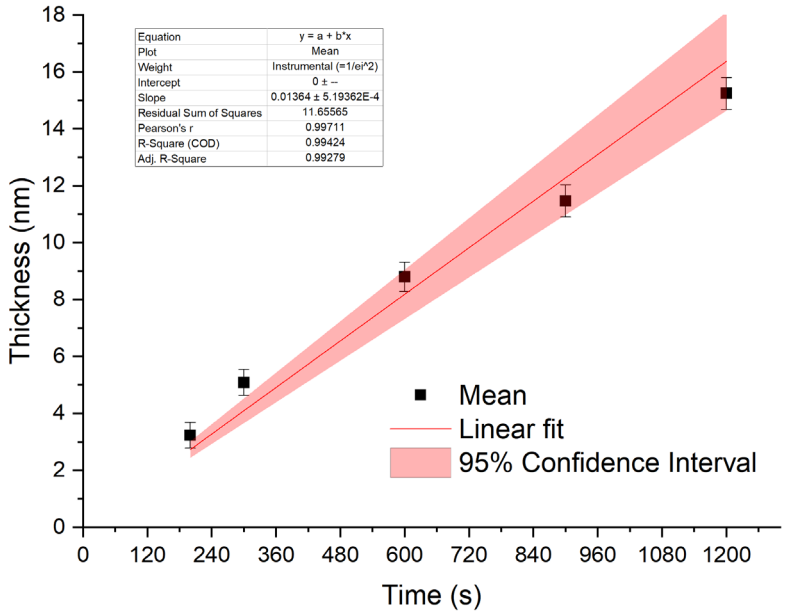
Fe calibration

Quartz Microbalance



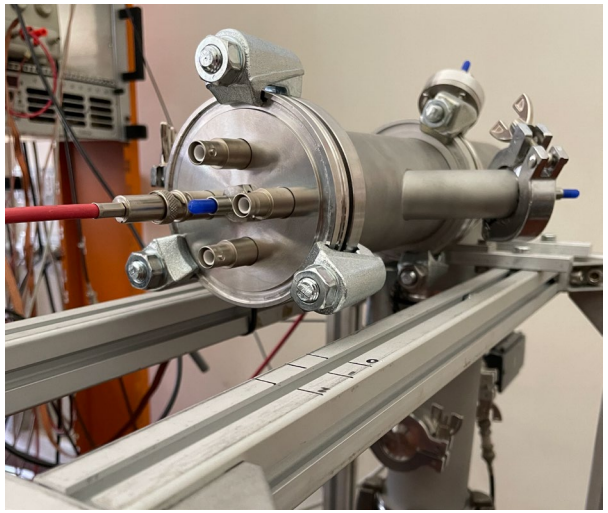
$$\phi(z_1) = \phi(z_2)\left(\frac{z_2}{z_1}\right)^2$$

$$= 0.05 \pm 0.01\,\frac{\text{Å}}{s}\left(\frac{133}{83}\right)^2 = 0.15 \pm 0.03\,\frac{\text{Å}}{s}$$

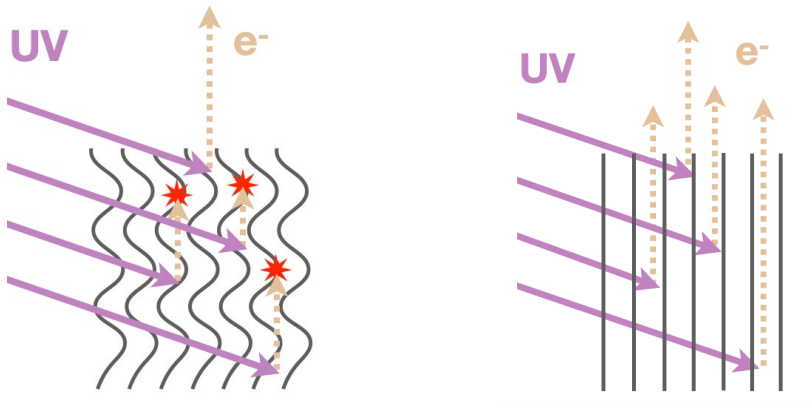


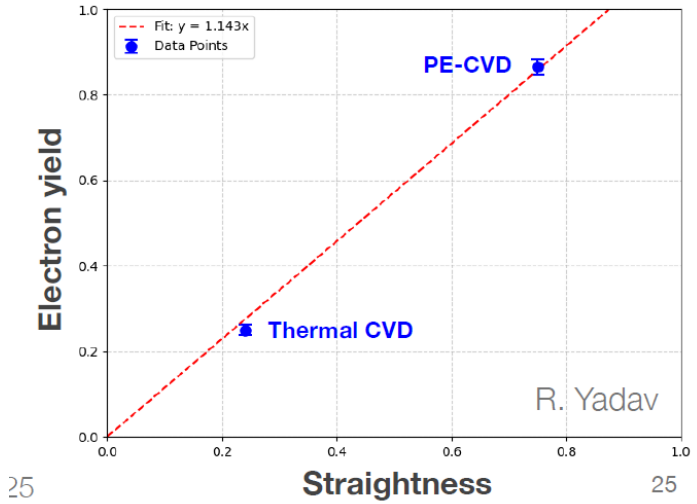
1st solution: PECVD

- UV Photoemission, shooting UV photons on nanotubes
- $E_\gamma = 5$ eV > $\Phi_{CNT} = 4.7$ eV
- More electrons are extraxted from straighter tubes



Photoemission apparatus Hyperion-II @ TitanLab





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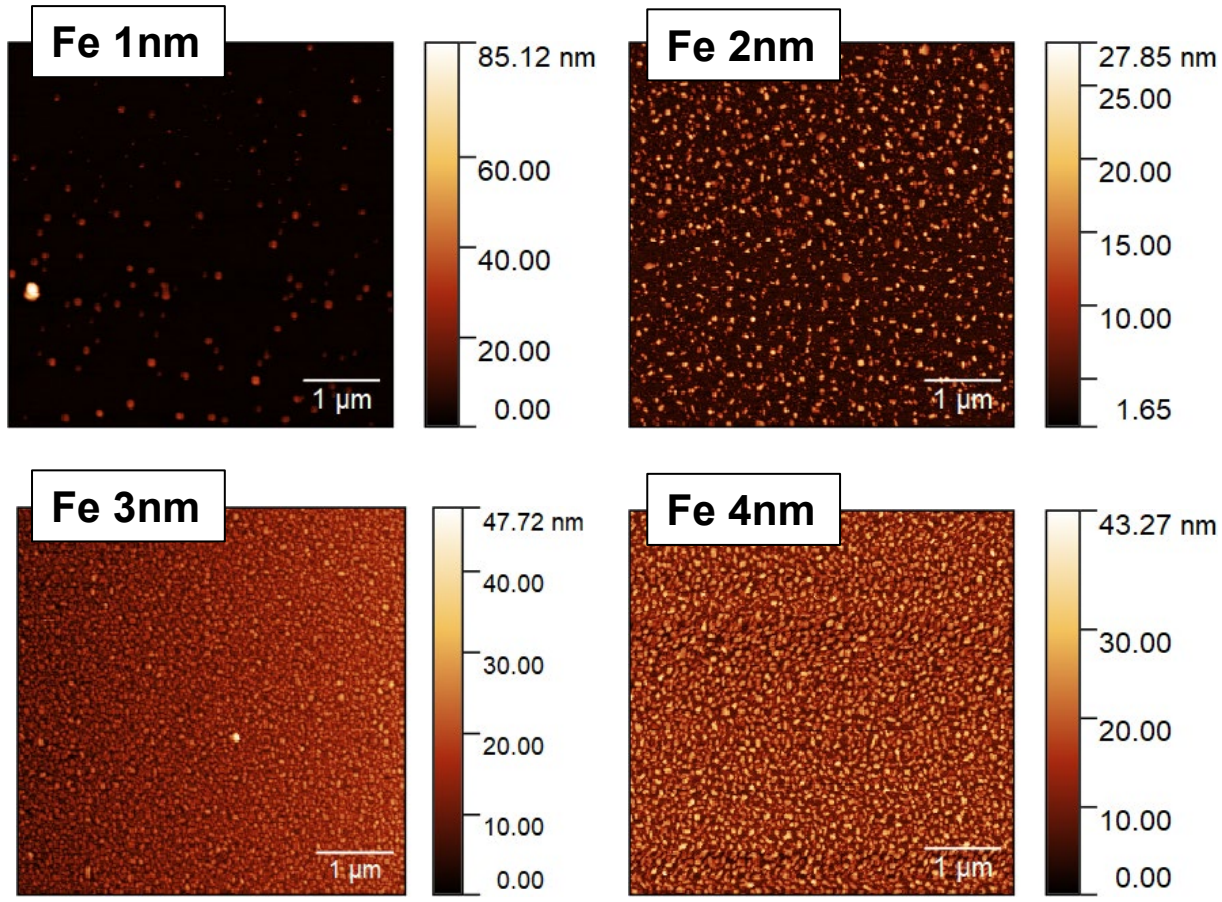
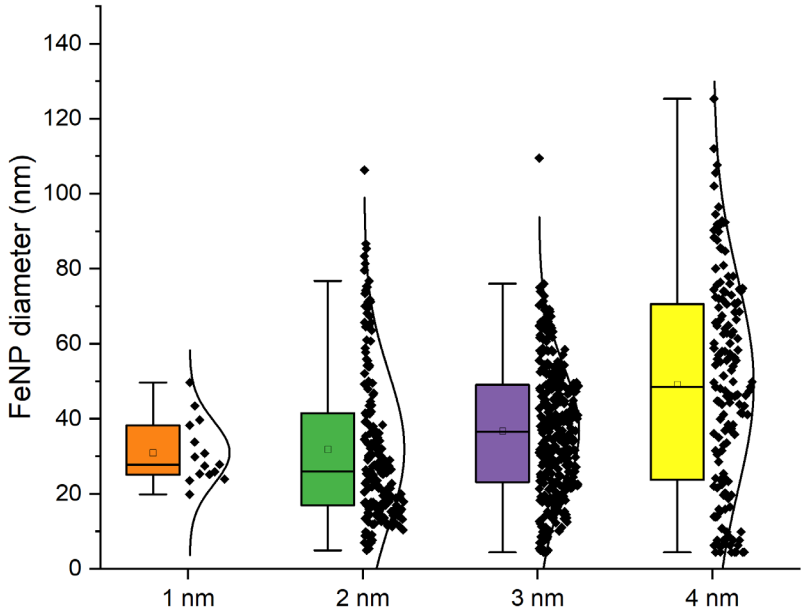
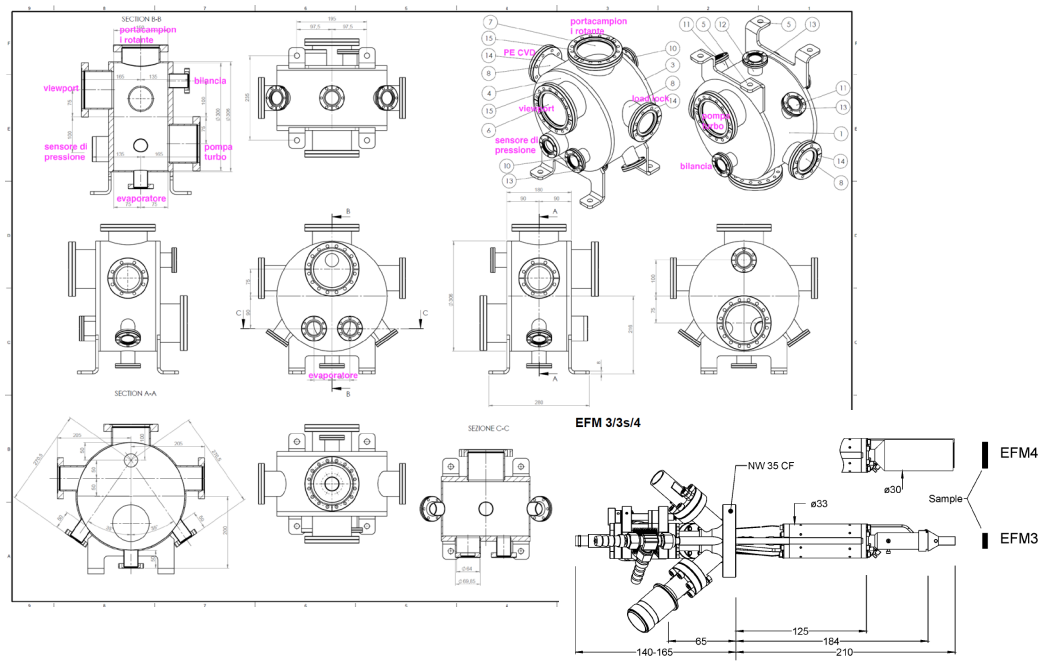
2nd solution: Nucleation sites

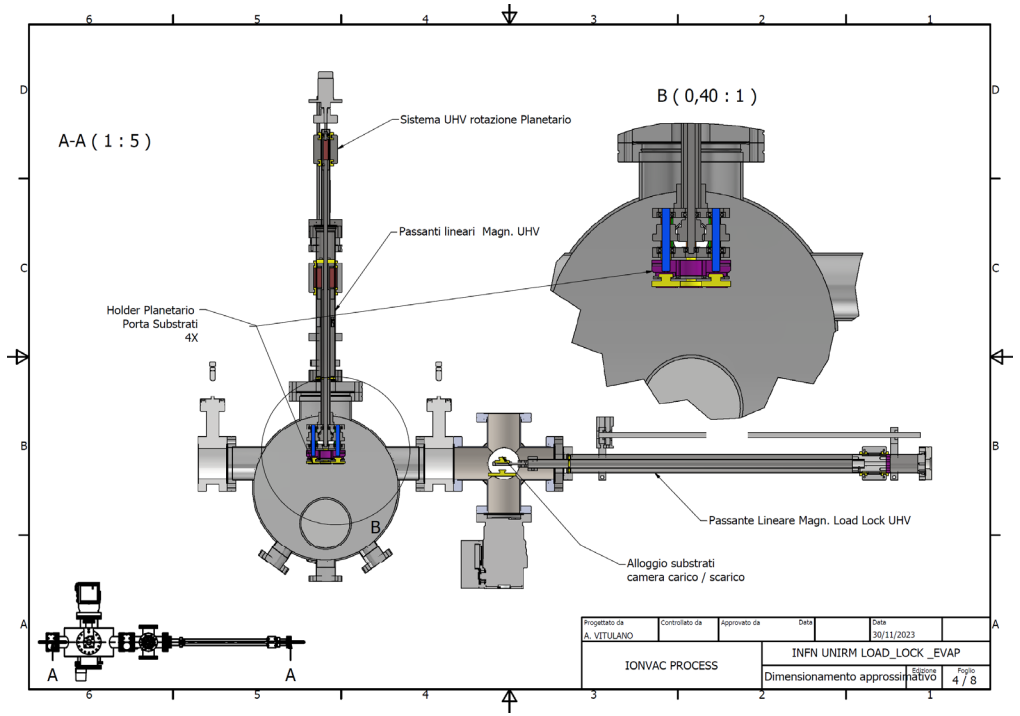


- Study morphology of FeNPs, reaching dense nanoparticles with diameter < 20nm.



E-beam Evaporator





Chemical Vapor Deposition