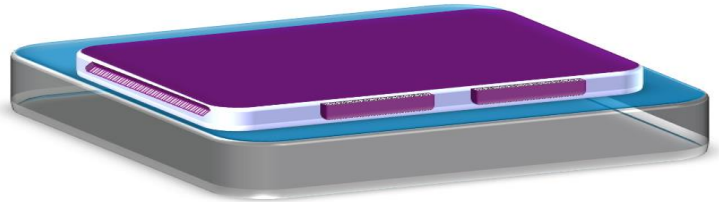

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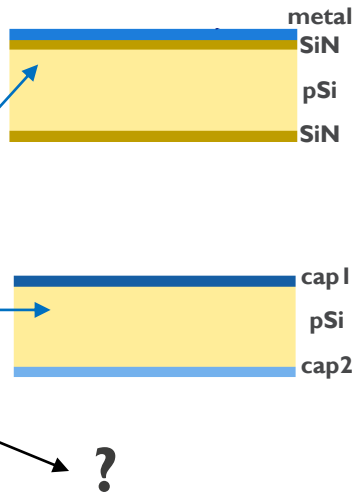
INTRODUCING THE EUV CNT PELLICLE

E. GALLAGHER, C. HUYGHEBAERT, J.U. LEE, I. POLLENTIER,
M. TIMMERMANS, H. ZAHEDMANESH

BACKGROUND
SOLUTIONS EXIST FOR LOW POWER

- Initial solutions exist for pilot/product phases, but are not viable for high powers

	Product Phase	Target specifications: Transmission	Transmission non-uniformity	Power capability
Pellicle film generations	Pilot	>80%	1%	>125W
	Product	88%	0.4%	250W
	Future	≥90%	0.4%	>250W

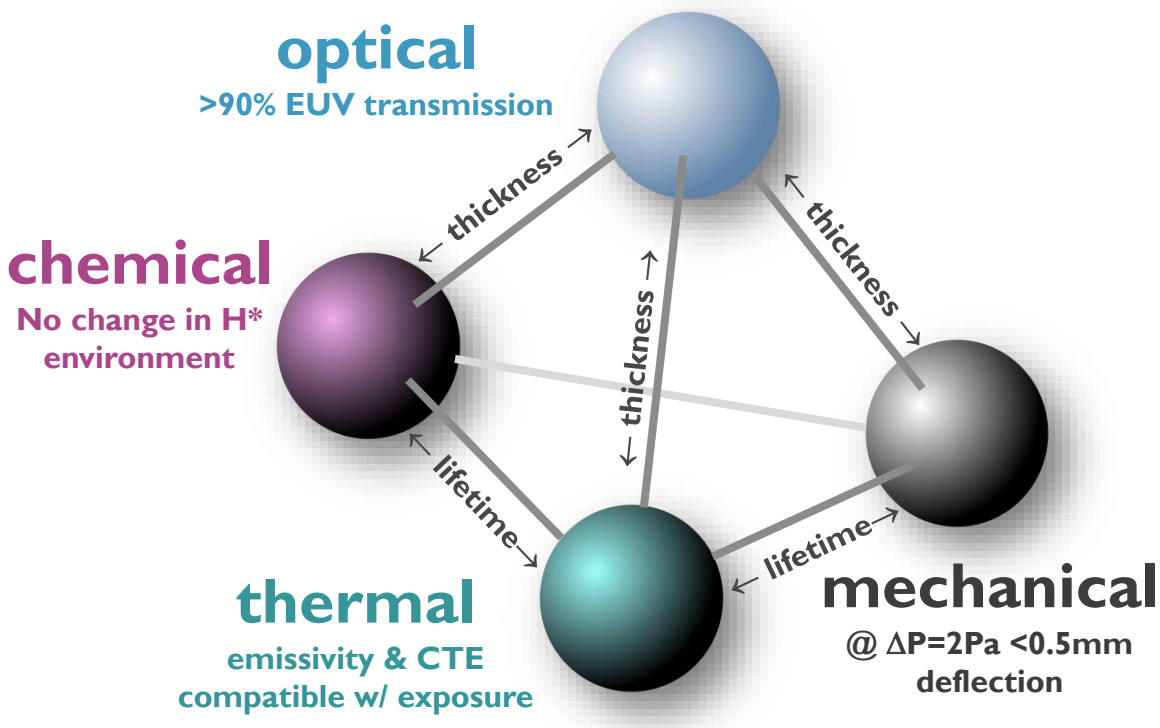


D. Brouns, et al. " NXE pellicle: development update", Proc. SPIE 9985, Photomask Technology 2016

Imec is developing a pellicle to meet ~>250W source power requirements

PELLICLE REQUIREMENTS
PYRAMID VIEW

- Layers added to improve chemical resistance or thermal properties reduce transmission
- Thicker layers are generally have improved mechanical strength
- Pellicle requirements are connected and must be balanced

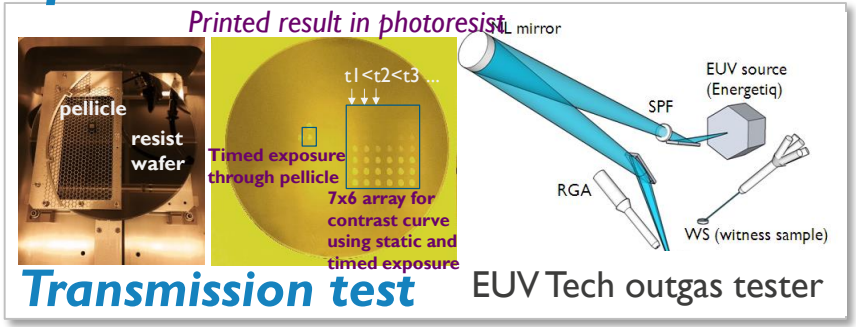


Pellicle membrane screening demands multiple metrology methods

PELLICLE TESTING SUITE @ IMEC

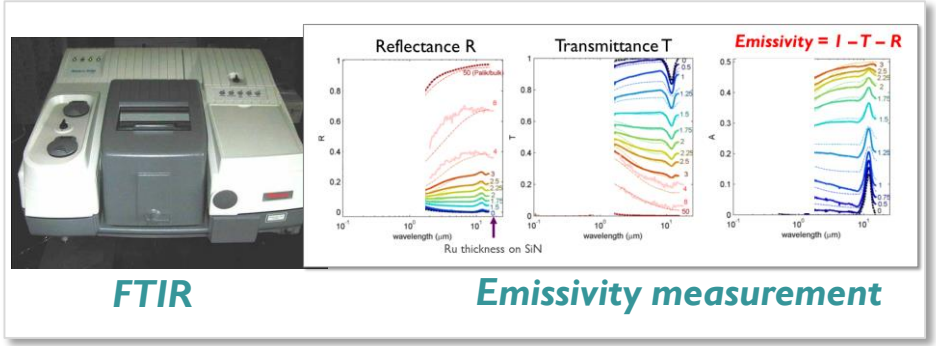
PLUS: RAMAN, XRD, MODELING, ..

optical



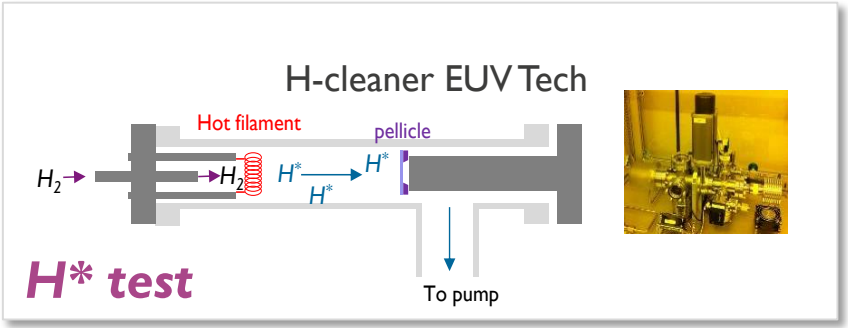
I. Pollentier, et al., EUVL Symposium (Maastricht, October 2015)

thermal



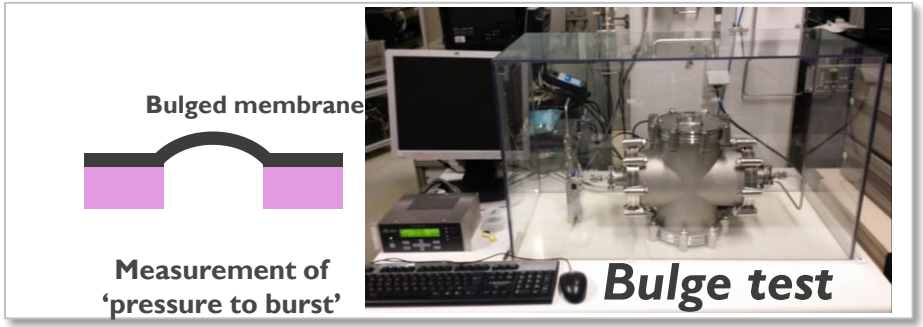
[P.J. Van Zwol (ASML), JAP 2015]

chemical



I. Pollentier, et al., EUVL Symposium (Maastricht, October 2015)

mechanical



J.U. Lee, et al., SPIE Photomask, (San Jose, September 2016)

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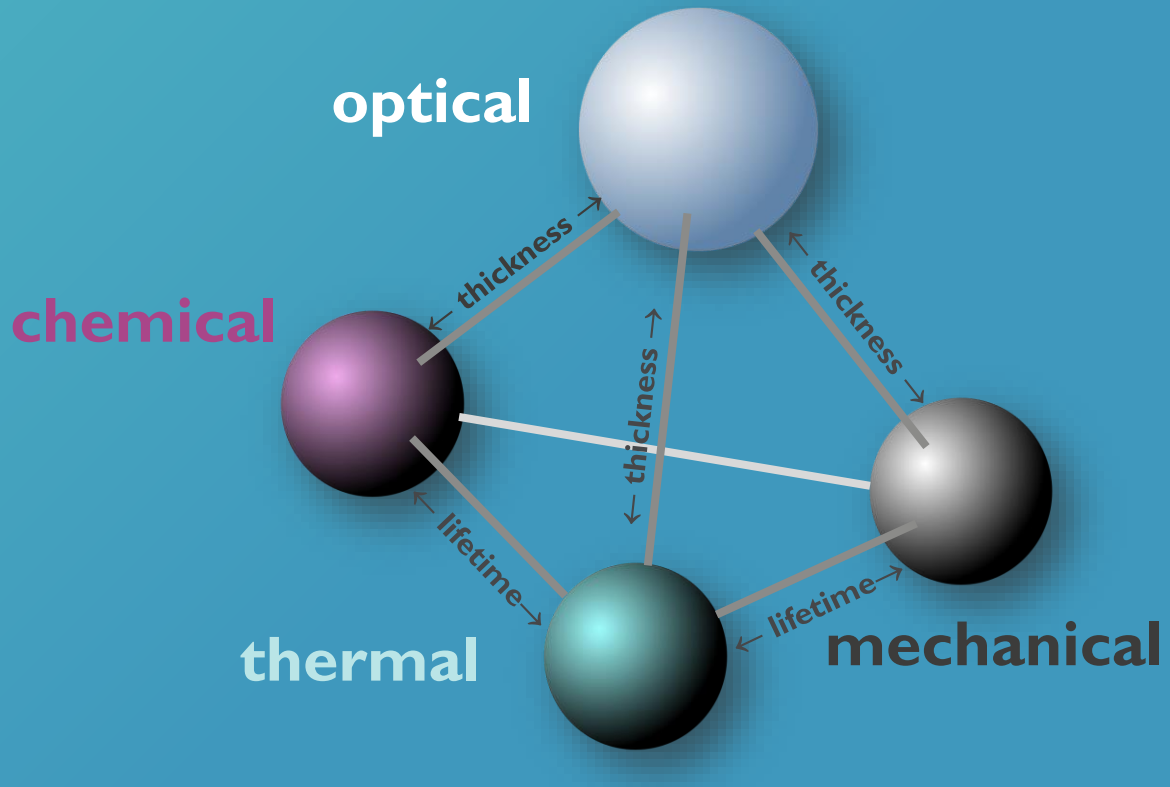
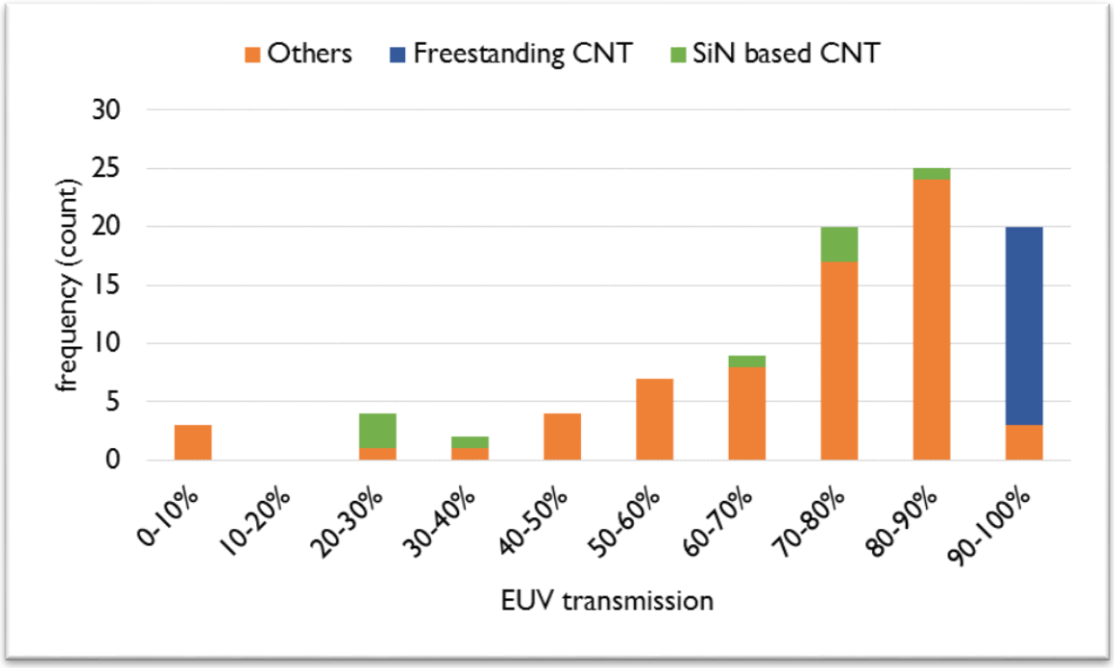
CNT-BASED PELLICLE
AND TRANSMISSION



WHY INVESTIGATE CNT-BASED PELLICLE MEMBRANES?

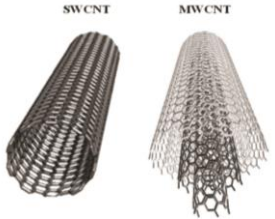
SAMPLES TESTED AT IMEC FOR PELLICLE APPLICATION



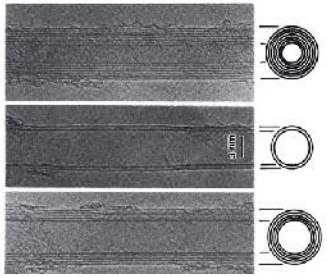
CNT without capping layer has very high transmission at EUV wavelengths

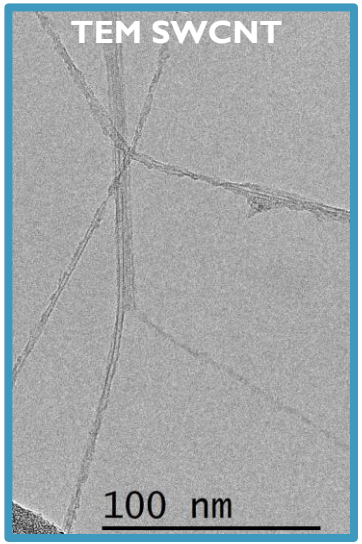
CNTS
BASIC FACTS

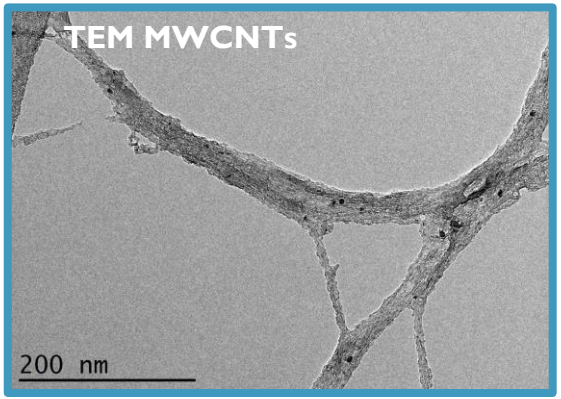
- CNT = sheet of carbon rolled into a cylinder
  - Single-walled (SWCNT): diamerter~1nm
  - Multi-walled (MWCNT): diameter ~5-30nm
  - CNT bundles can be long (>100 µm)
- General properties: strong, thermally stable, flexible platform for optimizing
- CNTs can form strong, ~2D network

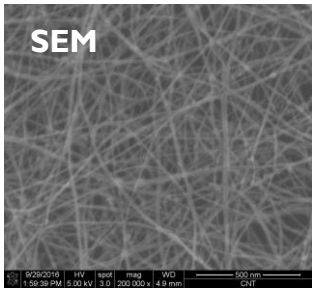


Sumio Iijima, Nature 354, 6348, 1991





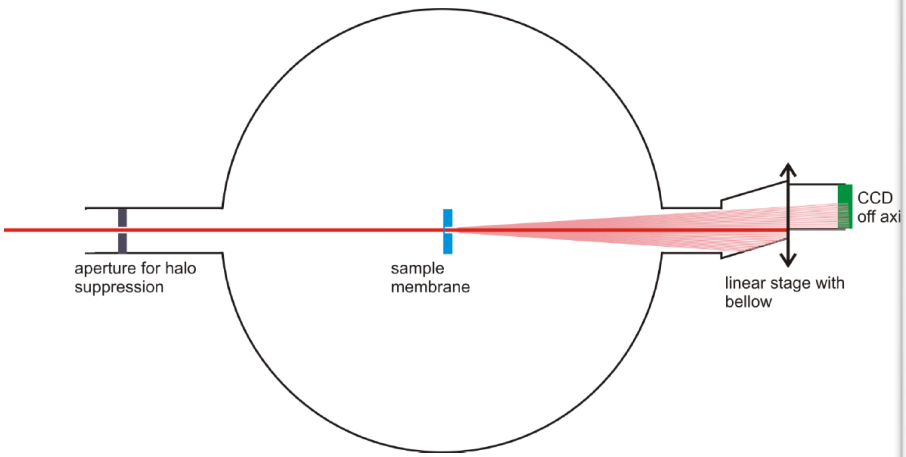


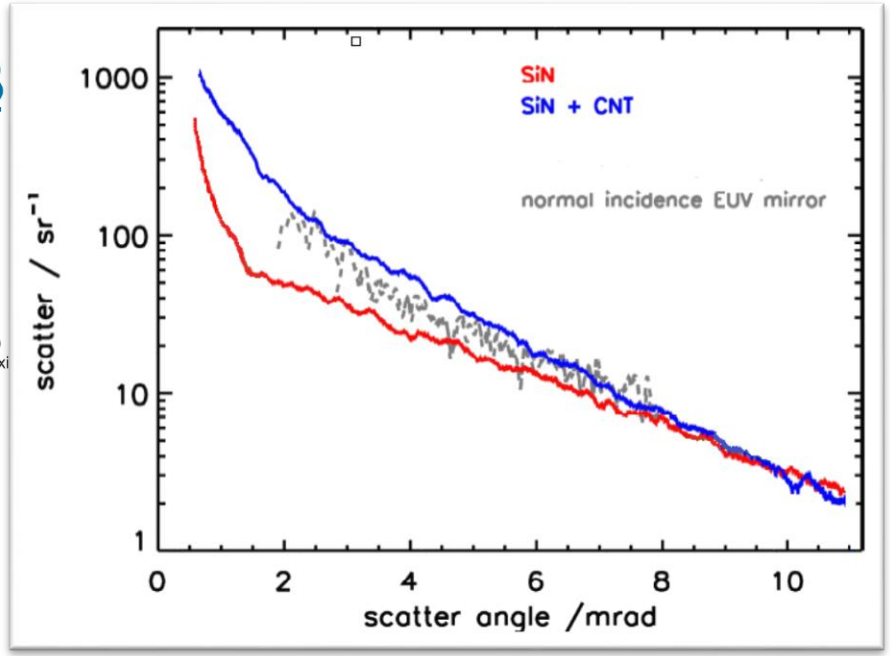


EUV SCATTERING FROM CNT FILMS

PTB SCATTERING MEASUREMENTS

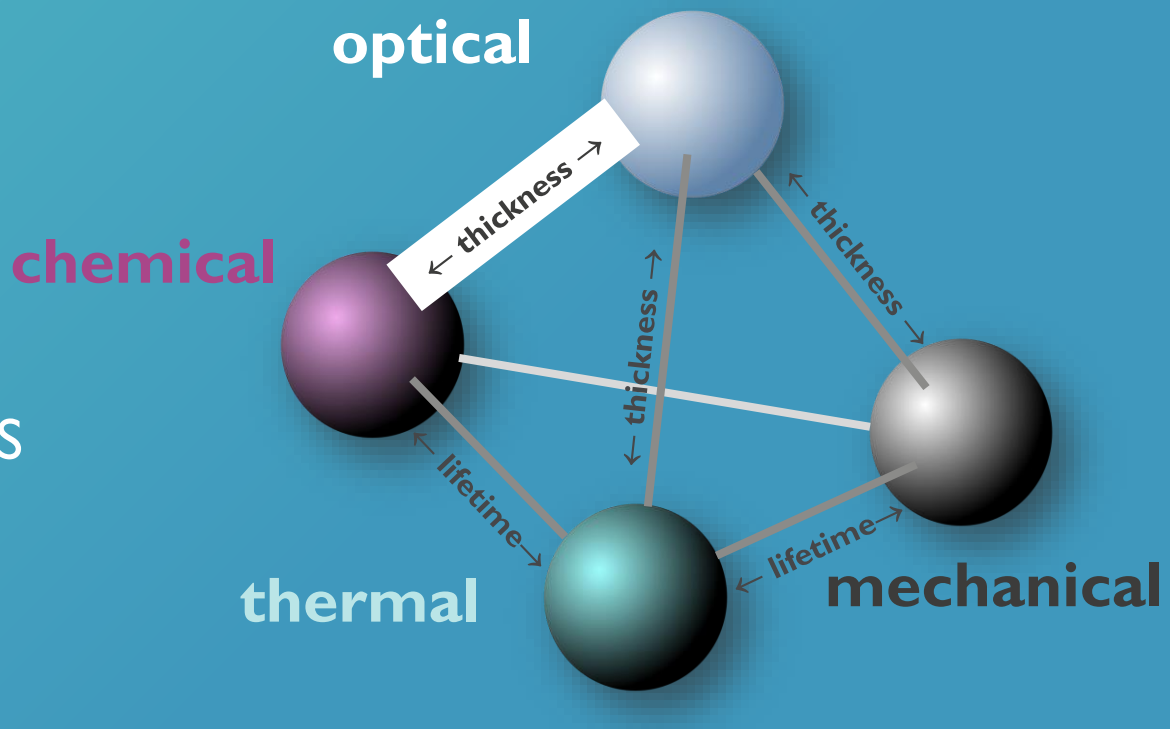
EUV scatter: scheme of measurement



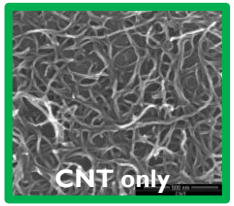


Small increase in scatter for SiN+CNT, but values are comparable to Si/Mo multilayer mirror surface.

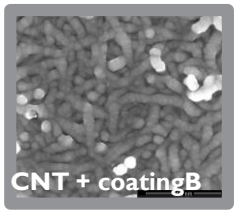
CHEMICAL TEST & COATING MEMBRANES

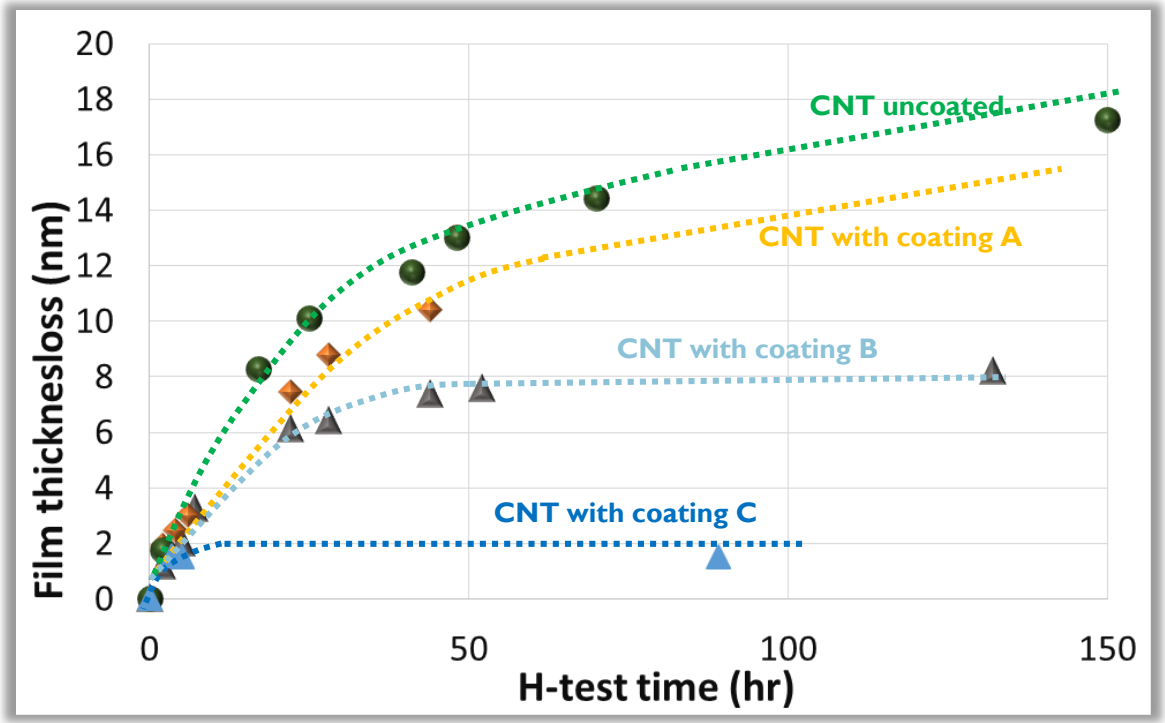


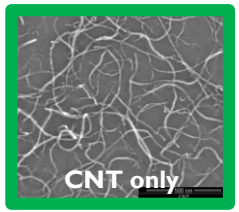
H* TEST: CAPPING LAYER IDENTIFICATION



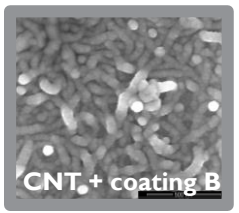
Before H*-test







After H*-test

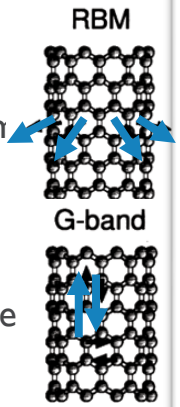


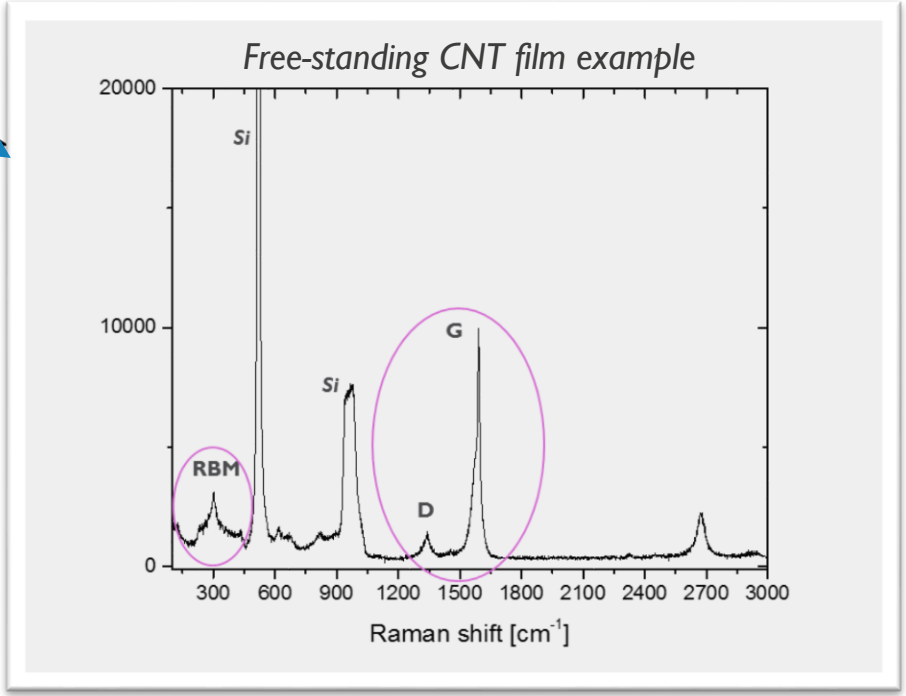
Coated CNT demonstrate flatter response after initial H* exposure.

CHANGE IN FILMS AFTER H* EXPOSURE

RAMAN SPECTROSCOPY

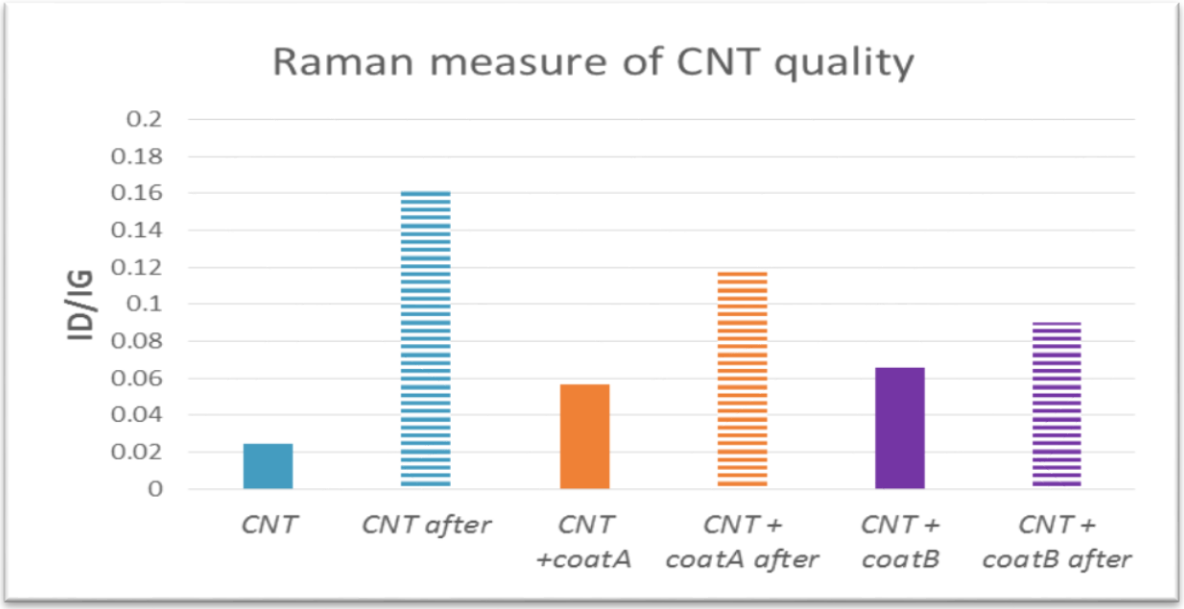
- Reading CNT Raman spectra
  - **RBM (**radial breathing mode): carbon aton move in-phase in the radial direction = SWCNTs
  - **G-band**: neighboring atoms are moving in opposite directions along the surface of the tubes
  - **D-band** (disorder-induced band): scattering from a defect which breaks the basic symmetry
- Intensity ratio D/G shows structural quality
  - Can be used to study changes





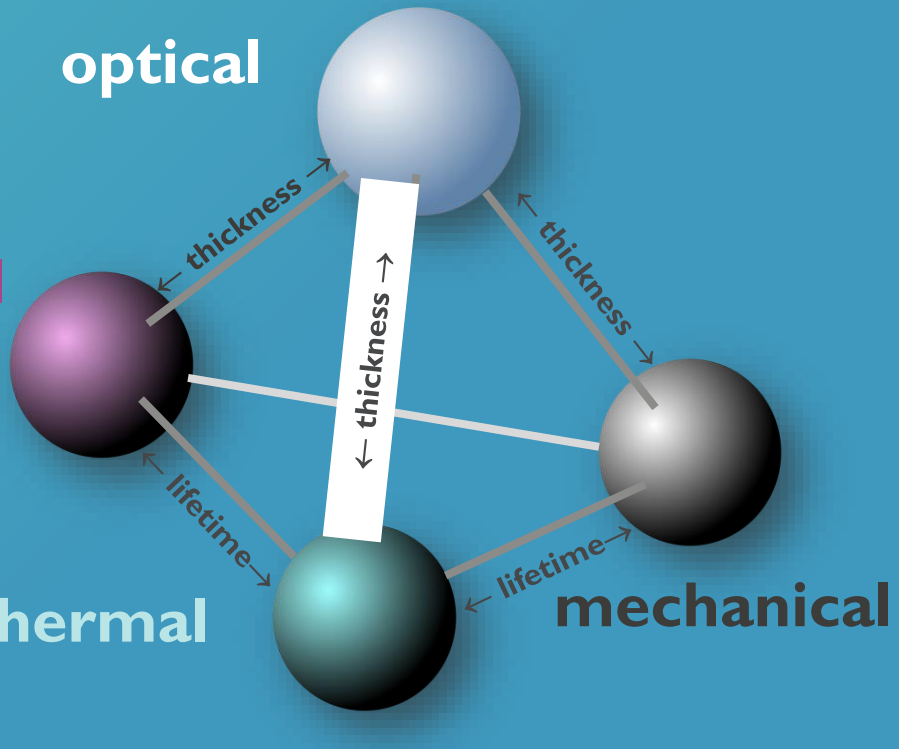
RAMAN CHANGES AFTER H* EXPOSURE FOR 130 HRS

LOW VALUES ARE BEST



While coating improves CNT resistance to H*, optimization is needed

THERMAL TESTING



HEAT & EMISSIVITY

FOURIER TRANSFORM INFRARED SPECTROSCOPY (FTIR)

- For thin membranes in vacuum, primary heat loss is through radiation (emission)

- At thermal equilibrium, absorption and emissivity ε are balanced (Kirchhoff's Law)

  $\varepsilon = A = 1 - R - T$

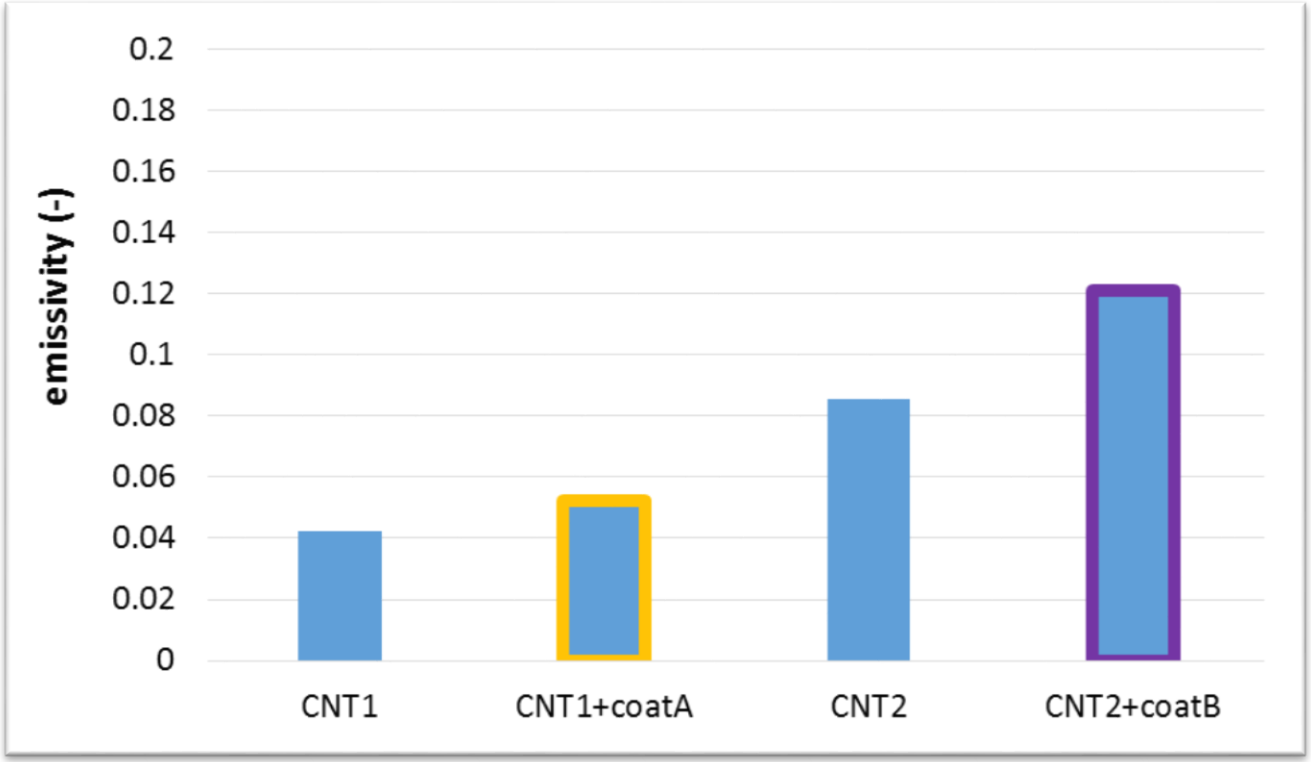
  values for ε *0=vacuum; 1=perfect black body*

- Commercial FTIR system enables emissivity measurements

pellicle membrane

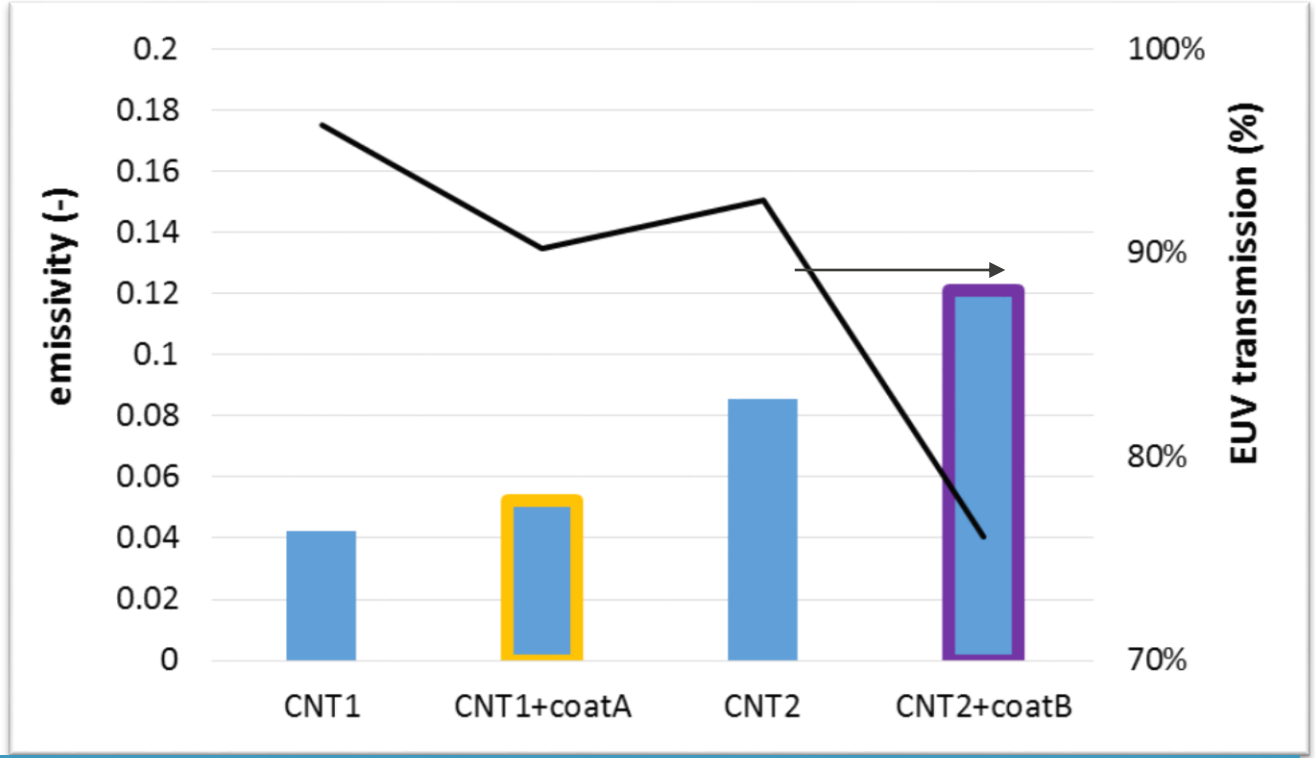
EMISSIVITY MEASUREMENTS

TWO CNT-COATING SAMPLES



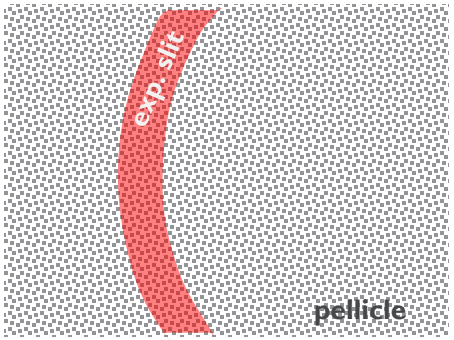
EMISSIVITY OF CNT-BASED PELLICLES

TRANSMISSION INCLUDED



Improving emissivity cannot be at the penalty of too much transmission loss

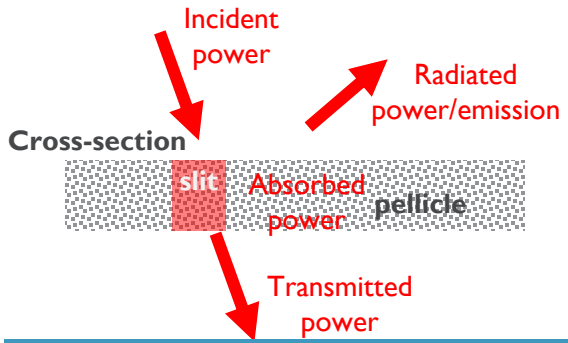
OPTICAL AND THERMAL CONNECTION



Power P is primarily transmitted or absorbed. In steady state, ~ all absorbed power is radiated (emissivity)

transmission = 1 – absorption

$$e^{-\alpha d} = \text{transmission} = 1 - \varepsilon \sigma S \frac{T_{max}^4 - T_0^4}{P}$$



d = pellicle thickness
α = absorption
ε = emissivity
S = slit area = 10^{-3} m^2

P = power at reticle level = 0.2 · P_{source} (W)
σ = Stephan-Boltzman constant = 5.67×10^{-8} W m^{-2} K^{-4}
T_0 = room temperature (~300K)
T_{max} = steady state pellicle temperature (K)

At 250W, there is a relationship between transmission, maximum temperature & emissivity

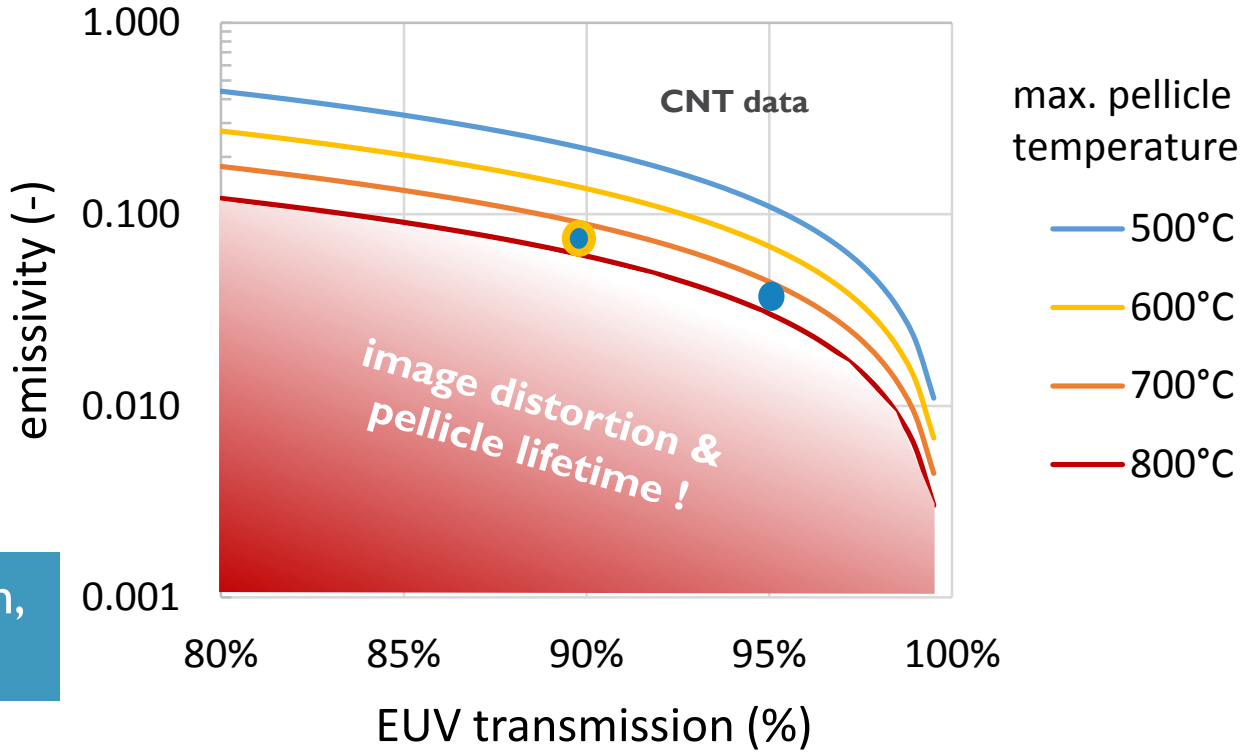
THERMAL & TRANSMISSION

EMISSIVITY AND HEAT

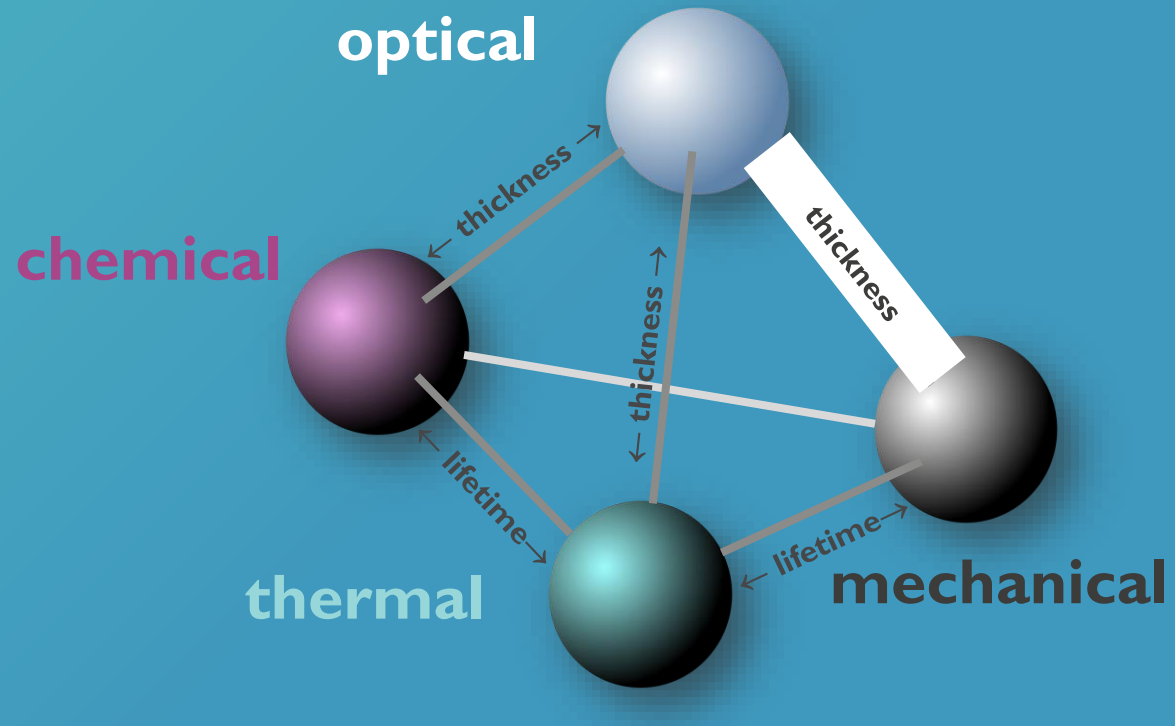
$$\text{transmission} = 1 - \varepsilon \sigma S \frac{T_{max}^4 - T_0^4}{P}$$

- 250W source power
- Emissivity as a function of transmission for different maximum temperatures
- CNT examples added

If transmission is very high, emissivity can be lower

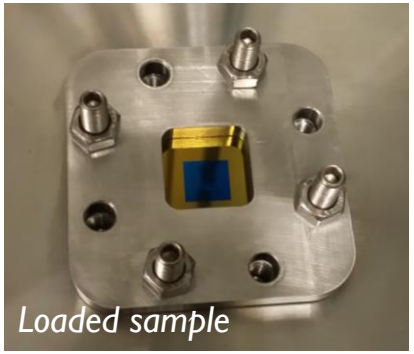


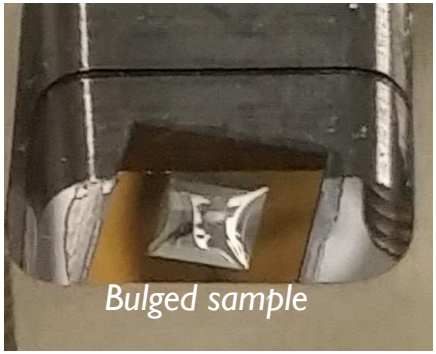
MECHANICAL TEST

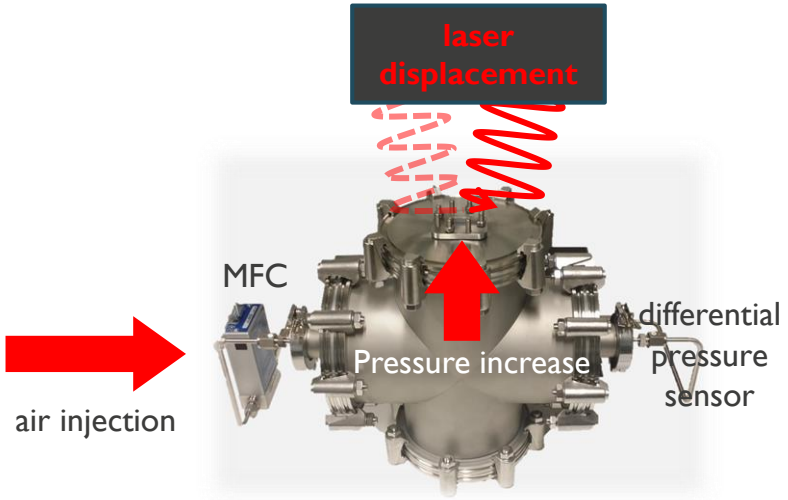


MECHANICAL: BULGE TESTER

1. Inject air to test membrane
2. Laser displacement measures deflection as a function of pressure
3. Record: displacement, pressure and pressure at failure (burst pressure)
4. Extract Young's modulus and intrinsic stress

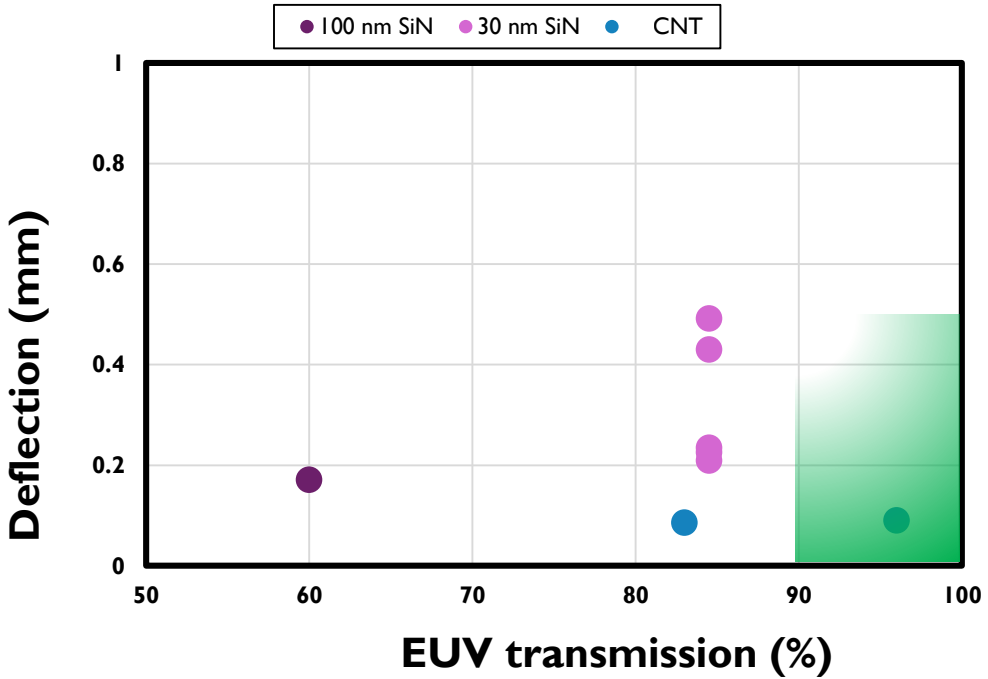






DEFLECTION OF PELLICLE : SIN VS. CNT

- Bulge test with 2.2 Pa/s flow
- Deflection value obtained
  - SiN : deflection at burst pressure
  - CNT : maximum deflection
- Compare deflection & transmission on the same chart

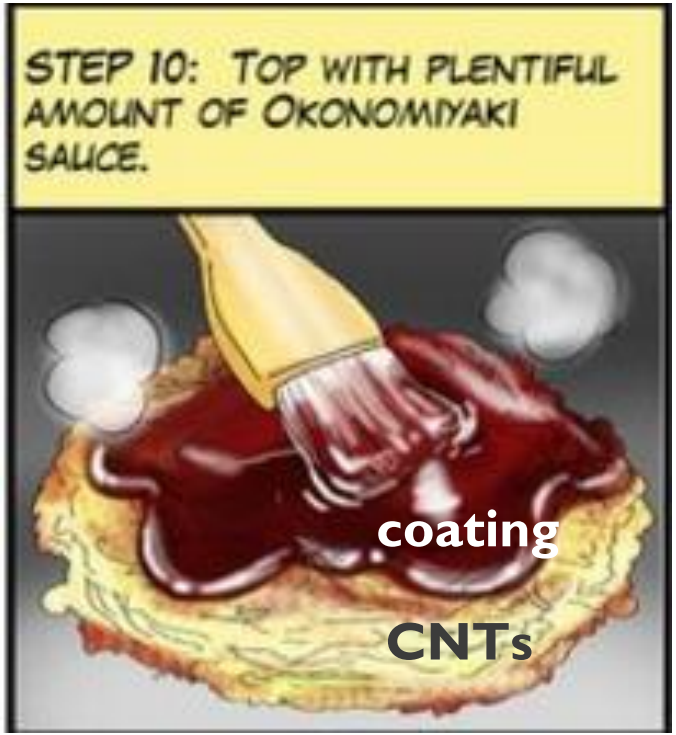


CNTs maximum deflection was less than 0.1 mm

SUMMARY

CLOSING THOUGHT
FOOD AND PELLICLES

- Fitting that CNT pellicles are discussed in Hiroshima, the city famous for its *Okonomiyaki*...



ACKNOWLEDGEMENTS

Thank you!

- Olivier Richard (imec) for TEM
- Elie Schapmans (imec) for ALD
- Arjen Klaver (ASM) for SiN
- Albert Nasibulin & Vsevolod Iakovlev (Skoltkovo Institute of Science and Technology, Moscow) for SWCNT samples
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- Frank Scholze and Christian Laubis (PTB) for scattering measurements
- Sascha Brose and Serhiy Danylyuk (RWTH) for EUV transmission uniformity

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