X-ray propagation in multiwall carbon nanotubes

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Structure of presentation

- Motivation for and background to the research
- Waveguiding in CNTs
- Reflectivity and x-ray modes in multiwall CNTs
- Bragg scattering and x-ray modes in coated multiwall CNTs
- Optimisation of Bragg structure
- Fabrication of CNTs for waveguiding
- Conclusions

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Motivation

- Semiconductor manufacturing is a multi-billion dollar industry.
- Nanoscale lithography will be very expensive.
- New photolithography tools are required for the fabrication of devices having nanometre scale dimensions.
- New characterisation tools are required.
- X-ray propagation in carbon nanotubes has the potential to provide a substantially cheaper alternative.

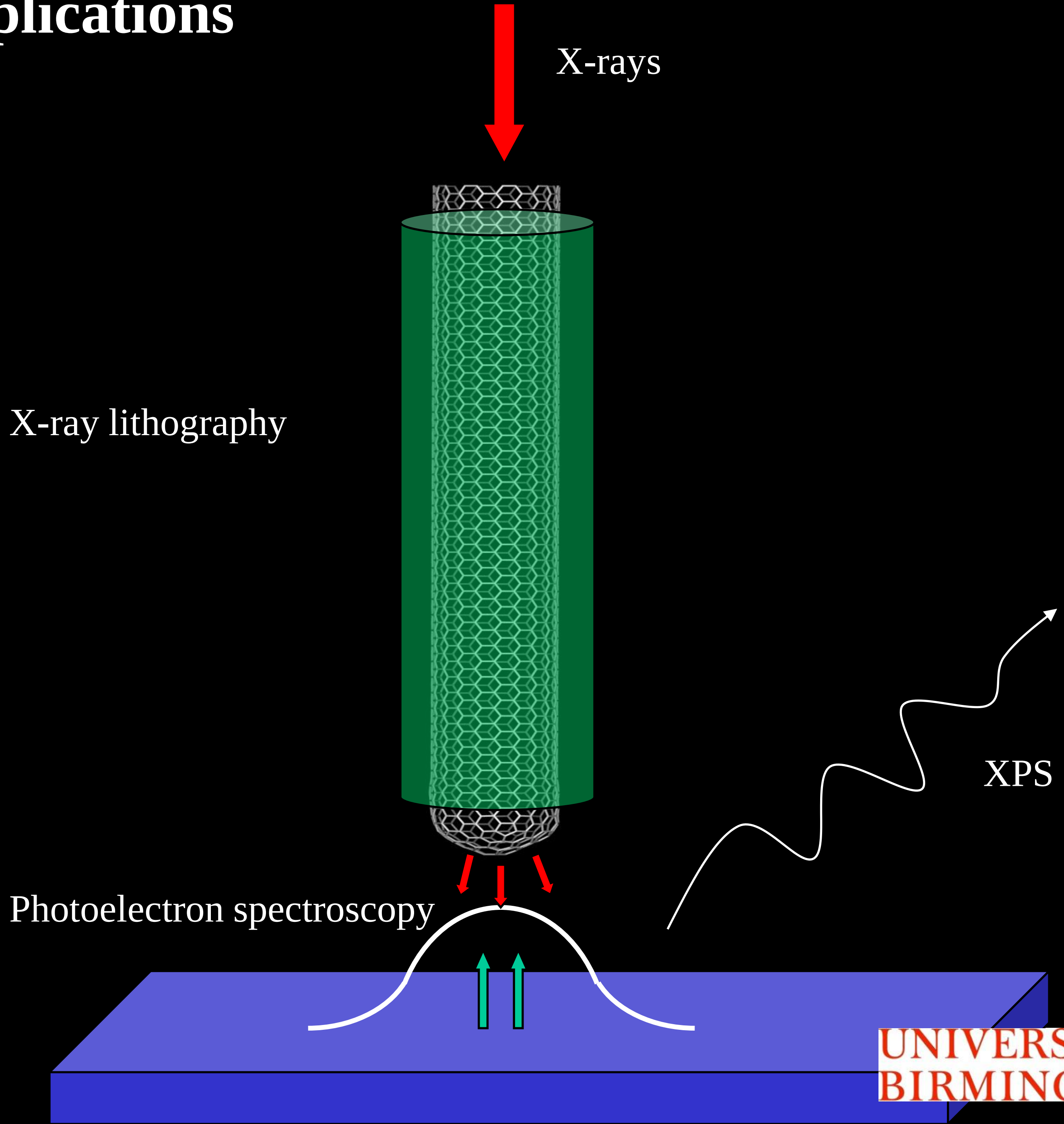
Background

- Possibility of channelling by neutral particles in carbon nanotubes postulated by Zhevago and Glebov (1998)

- Coherent propagation of x-rays demonstrated in a planar waveguide, Zwanenburg et.al. (1999)

- Recent demonstration of the growth of regular arrays of carbon nanotubes, Milne (Cambridge) and others.

Applications



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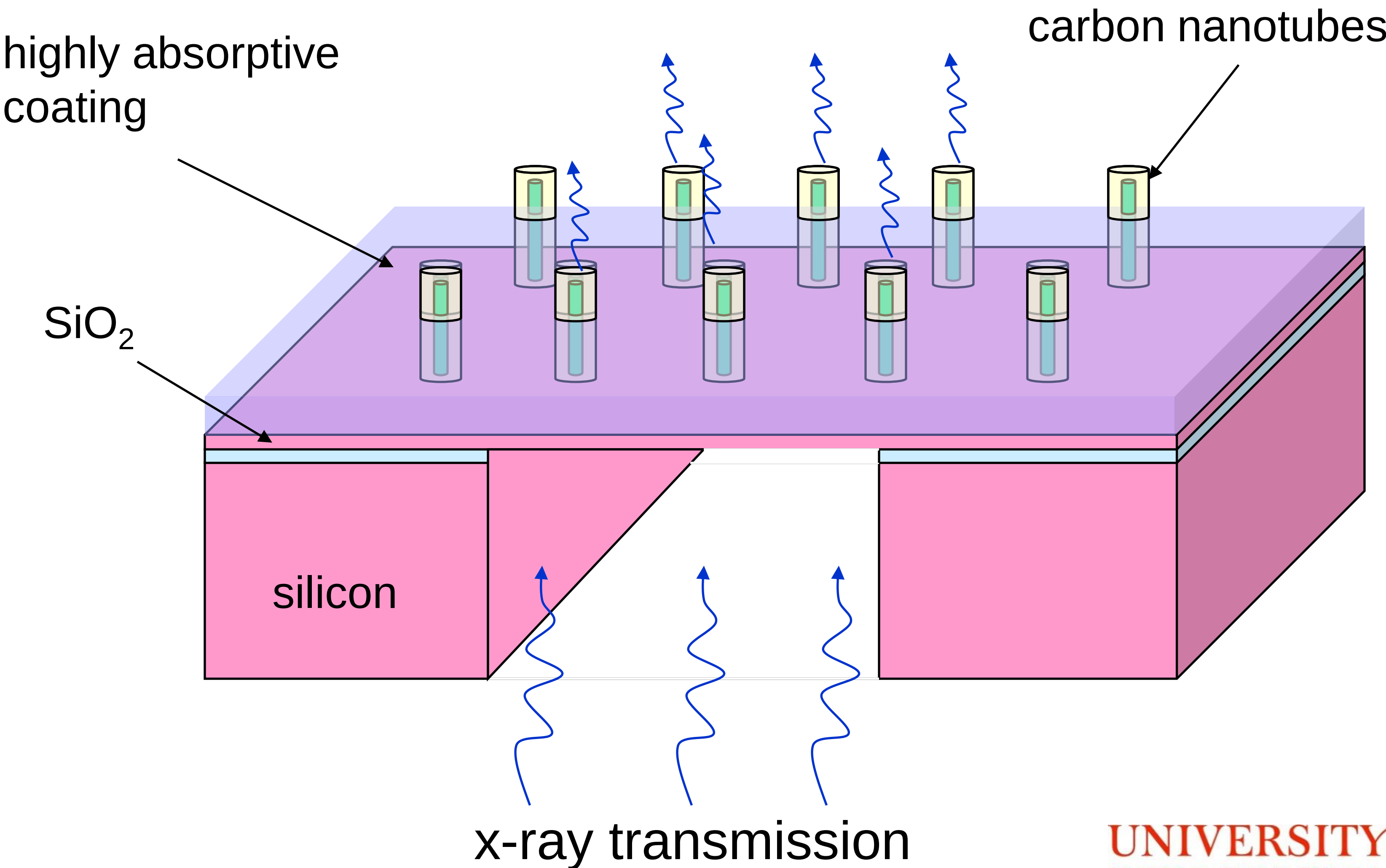
Structure of waveguide



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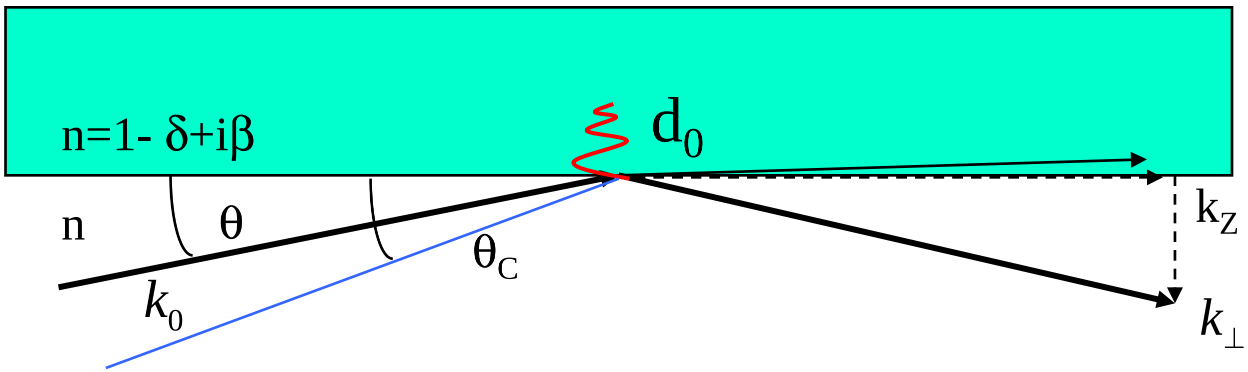
X-ray scattering at an interface

Reflection and field penetration of x-rays at an interface



Total external reflection occurs when $\theta < \theta_C$

And the critical angle θ_C is

$$\theta_C = \sqrt{2\delta} \quad \sim \text{mrad}$$

$$\delta = \frac{n_a r_e \lambda^2}{2\pi} f_1^0(\omega)$$

$$\beta = \ldots\ldots\ldots\ldots f_2^0(\omega)$$

penetration depth, d_0 ~ 6.4nm in carbon

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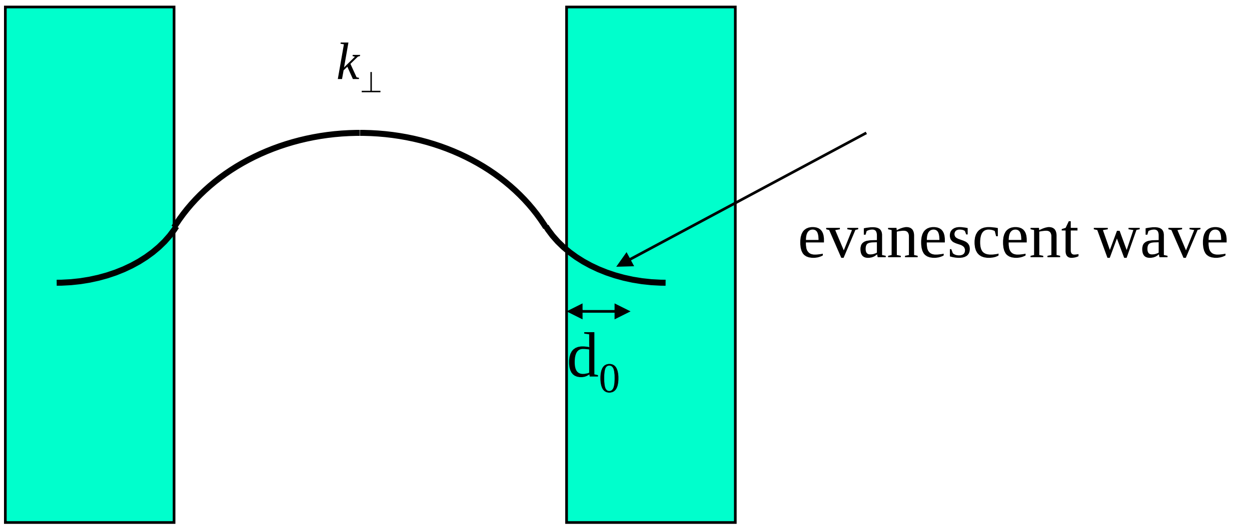
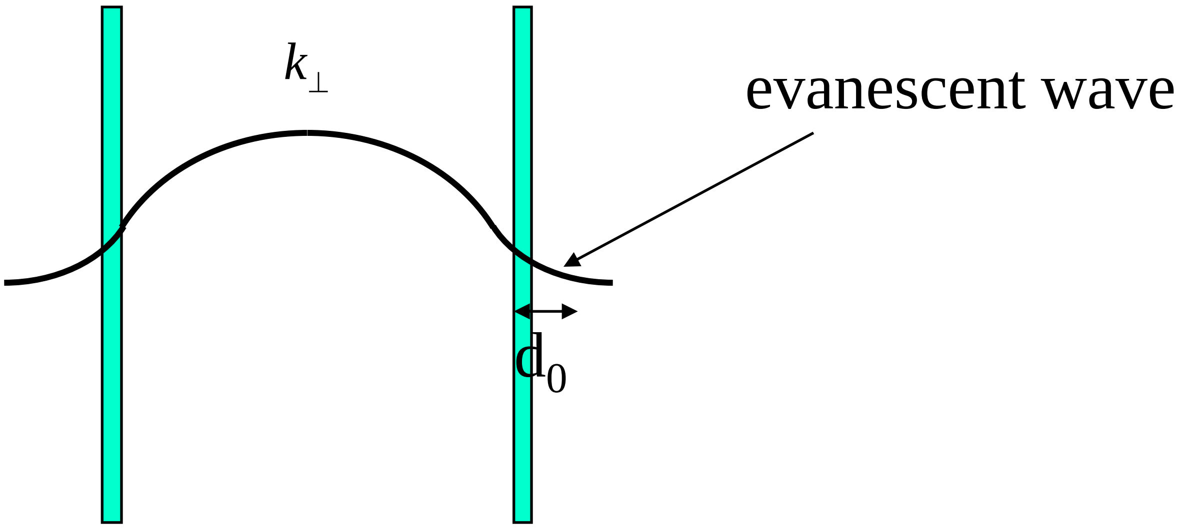
Propagation of x-rays in a planar waveguide



Field penetration depth, d_0 is given by

$$d_0 = \frac{\lambda}{2\pi\sqrt{2\delta}} = \frac{1}{2\sqrt{n_a r_e \pi f_1^0}} = 6.4nm \text{ (carbon, atomic number, Z=6)}$$

Propagation of x-rays in a planar waveguide



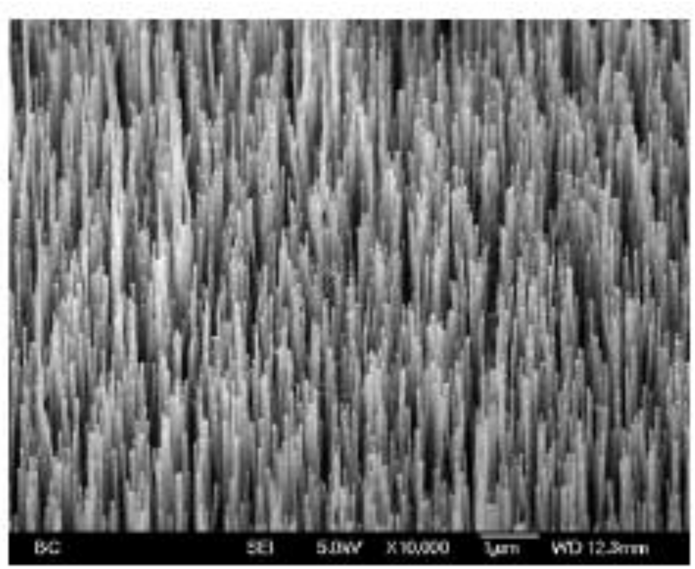
Field penetration depth, z_0 is given by

$$d_0 = \frac{\lambda}{2\pi\sqrt{2\delta}} = \frac{1}{2\sqrt{n_a r_e \pi f_1^0}} = 6.4nm$$ (carbon, atomic number, Z=6)

d_0 >> thickness of nanotube wall ~ 0.1 nm

Coating of CNT's demonstrated

Well ordered vertical nanotubes coated with polypyrole
J H Chen et.al., Appl Phys. A 73, 129 (2001)



Coating thickness 93 nm on carbon nanotubes
with diameter ~ 30 nm

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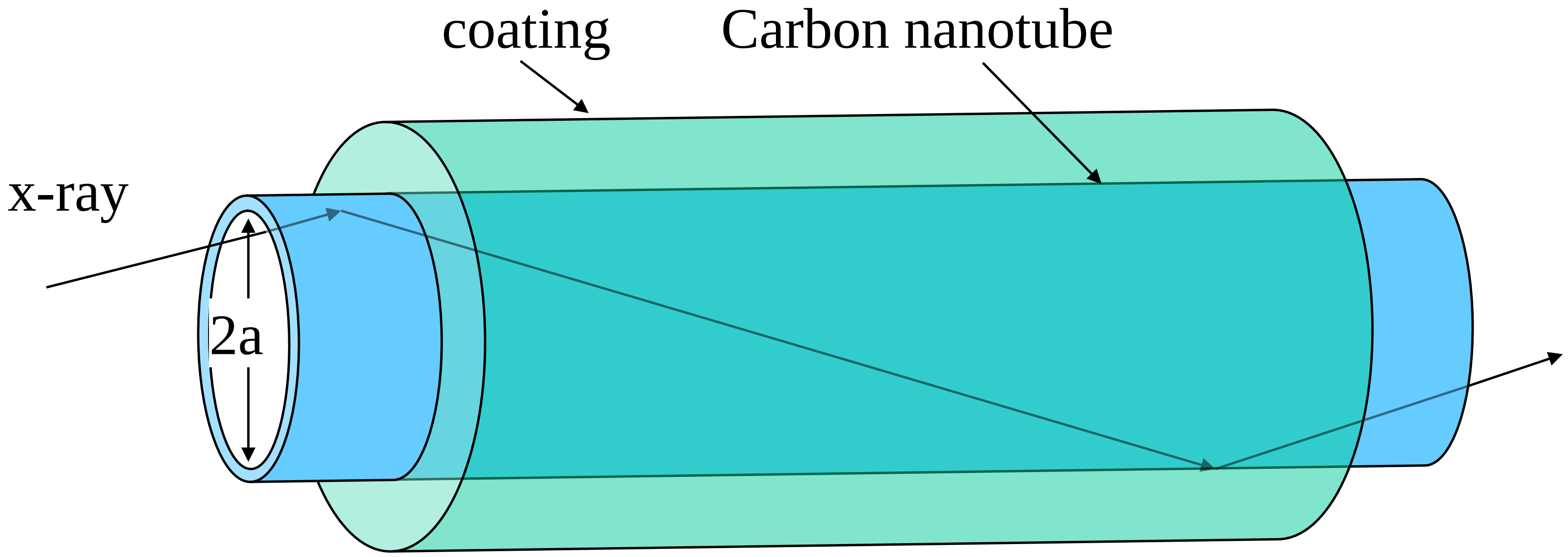
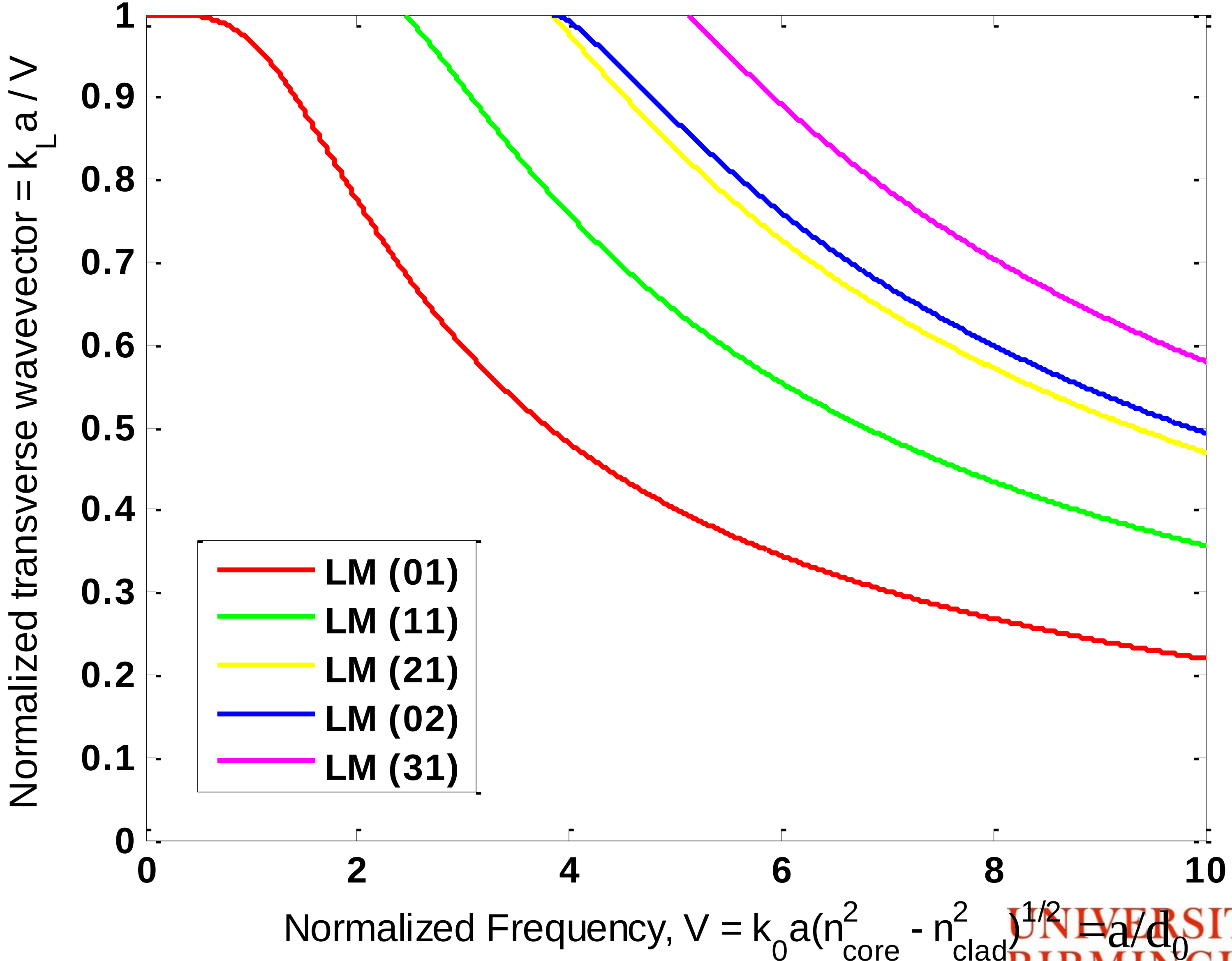
Propagation of x-rays in CNT's analogous to fibre optics



Refractive index ,n, of coating (cladding) = 1-δ   (δ ~ 10^{-4})

Low order modes in a coated CNT



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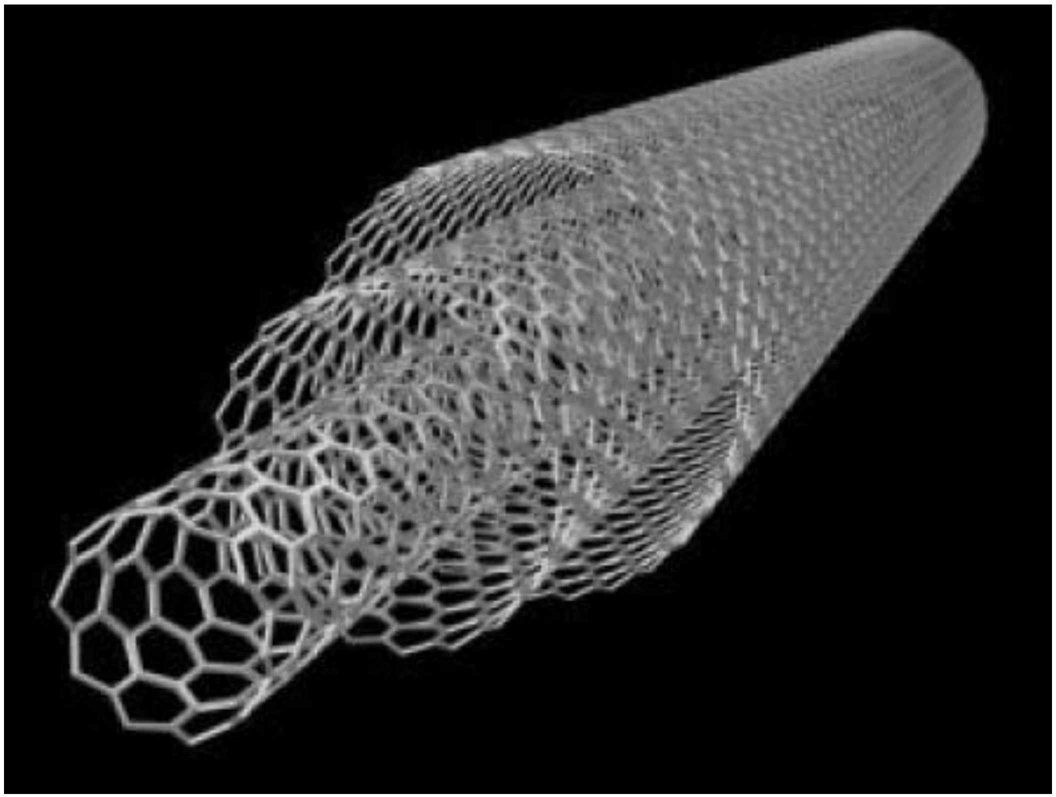
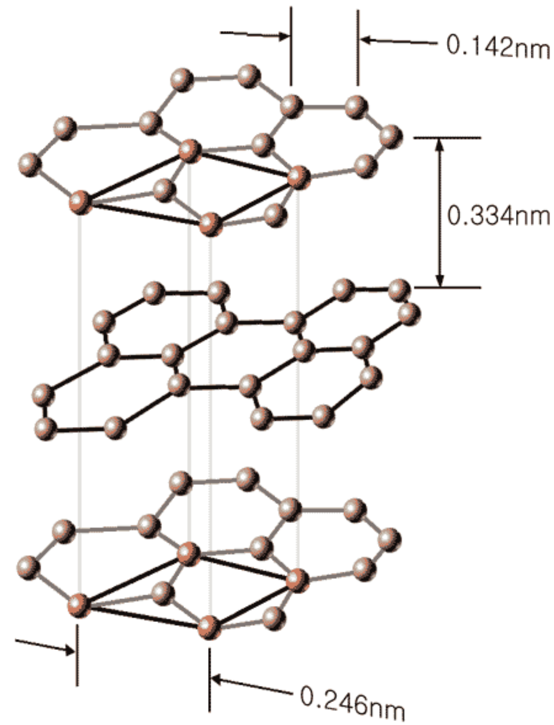
Multiwall CNT





A Loiseeau et. al, Understanding Carbon Nanotubes: From Basics to Applications
2006: Springer; 1st Edition

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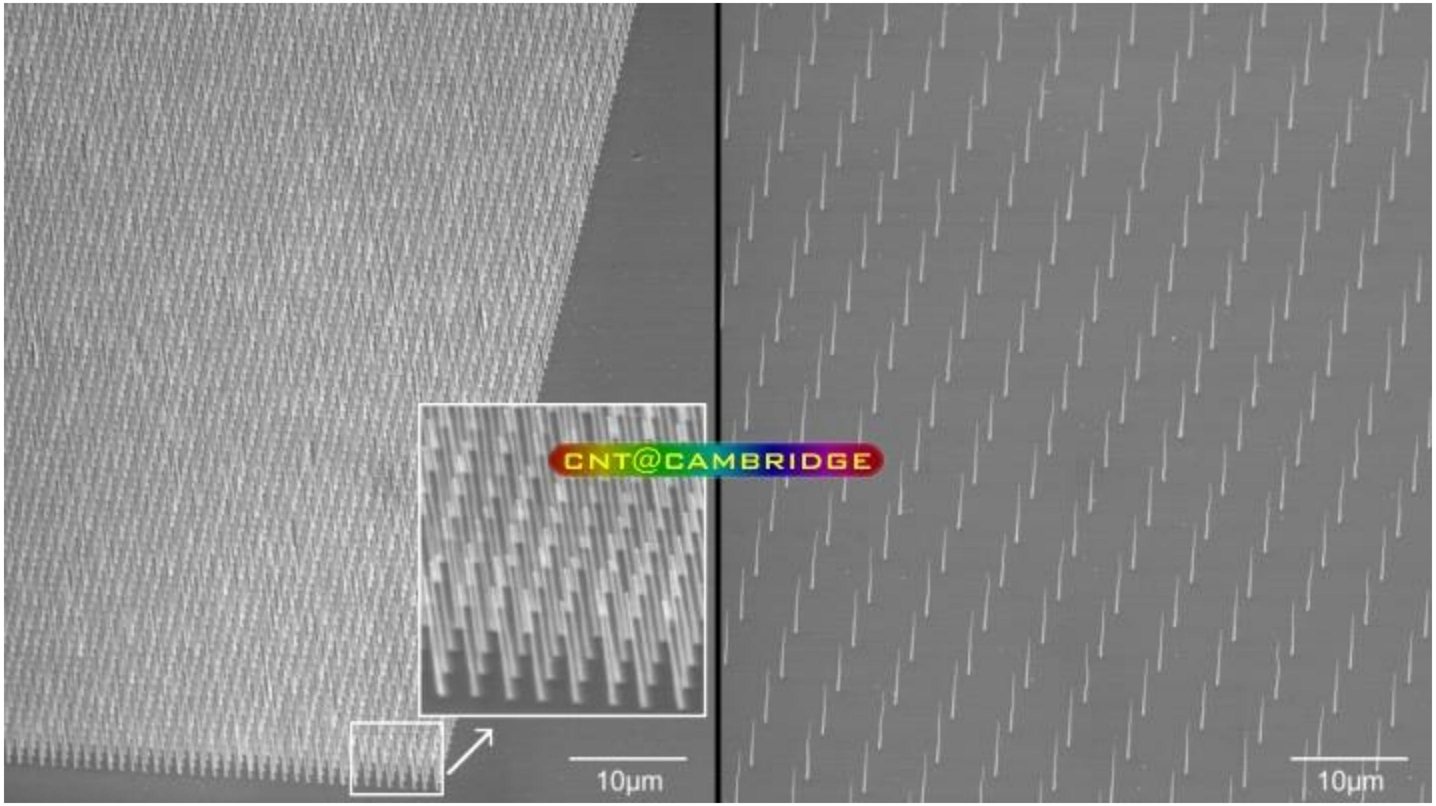
Growth of CNT's



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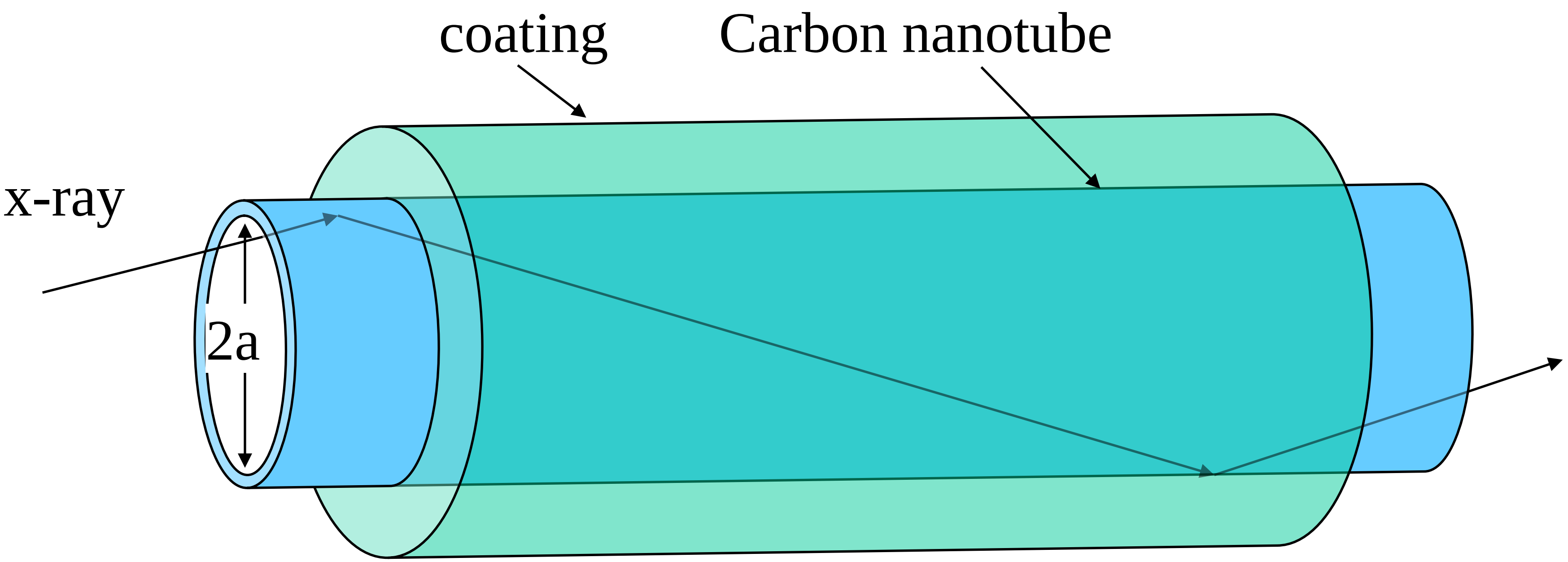
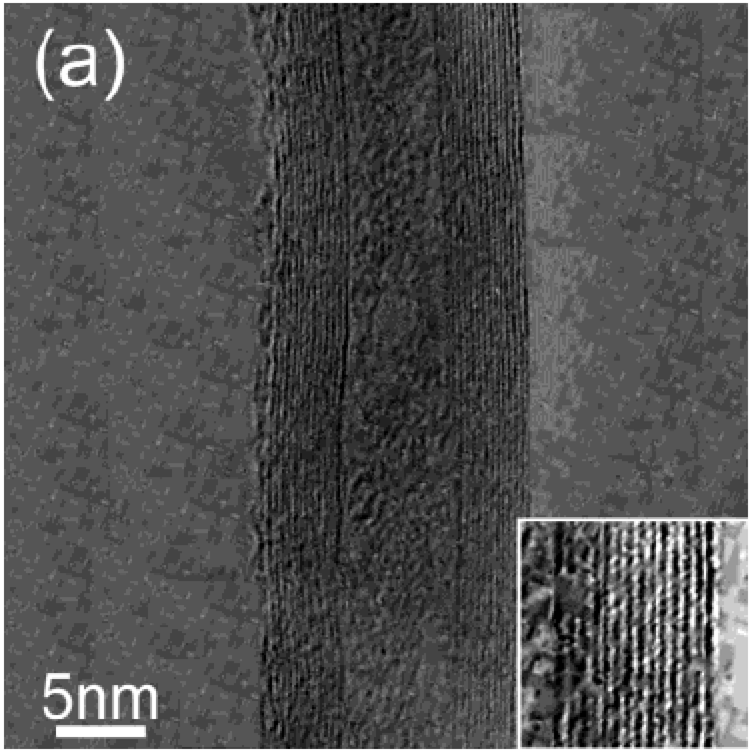
Propagation of x-rays in CNT's analogous to fibre optics



Refractive index ,n, of coating (cladding) = 1-δ ($\delta \sim 10^{-4}$)

Simulation of propagation propagation must take account of the Multiple walls



N S Kim et. al. J. Phys. Chem., **B** 2003, 107, 9249

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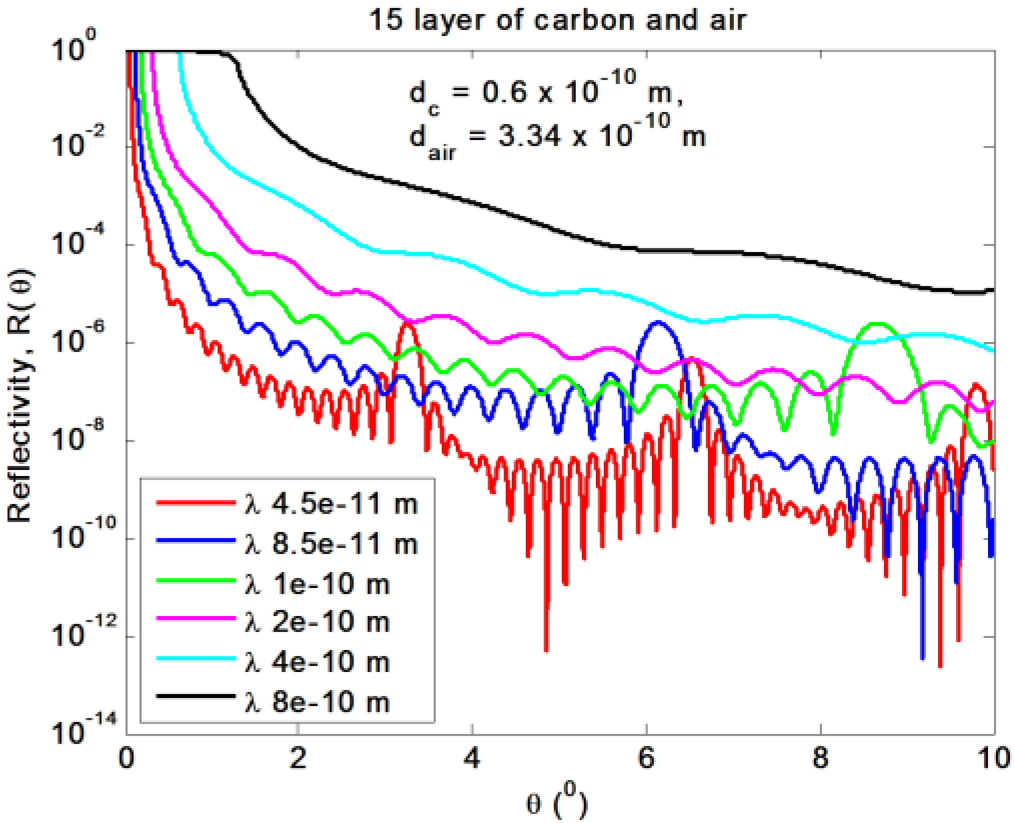
Reflectivity from 15 layers of C/Air as a function of incident angle and wavelength



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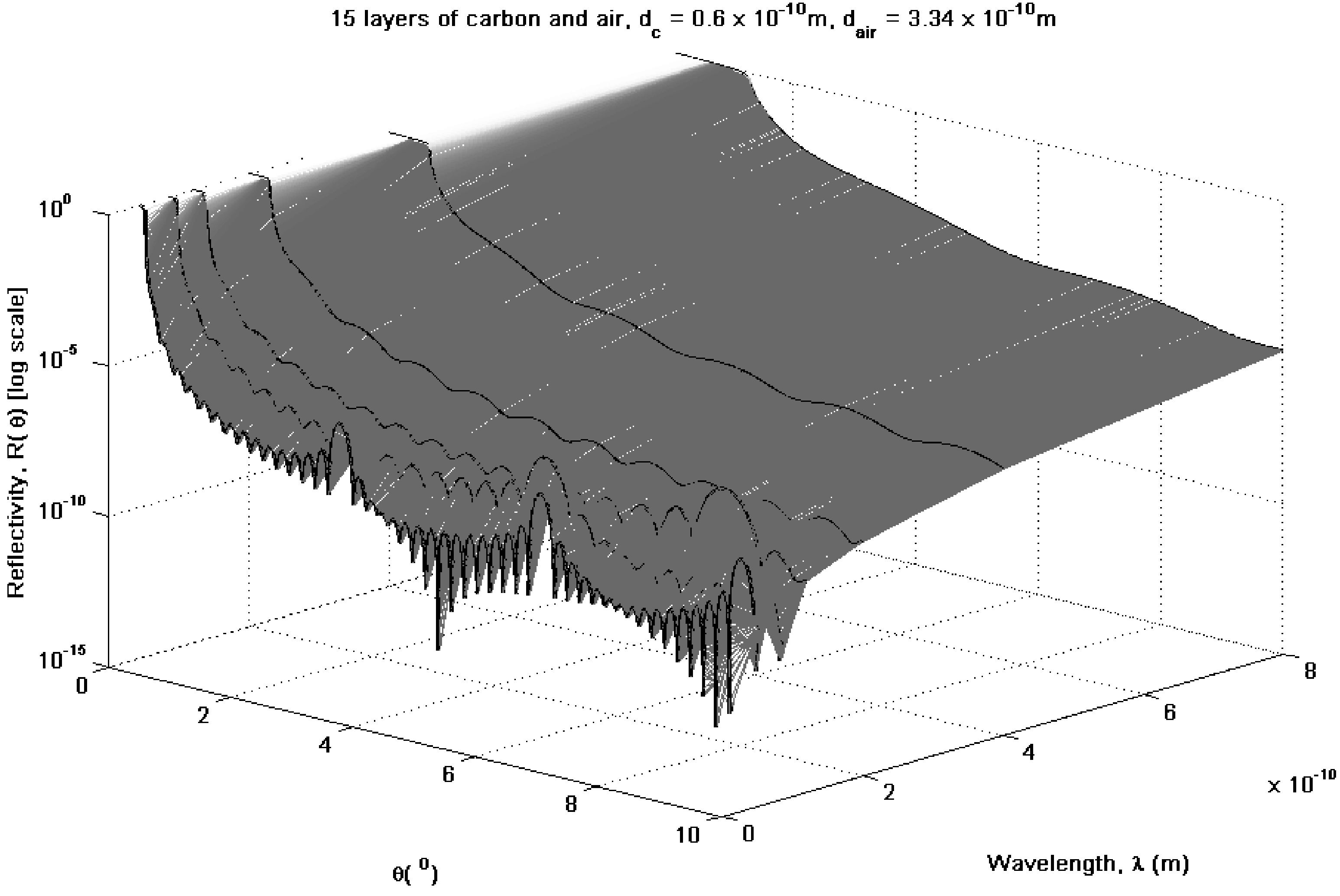

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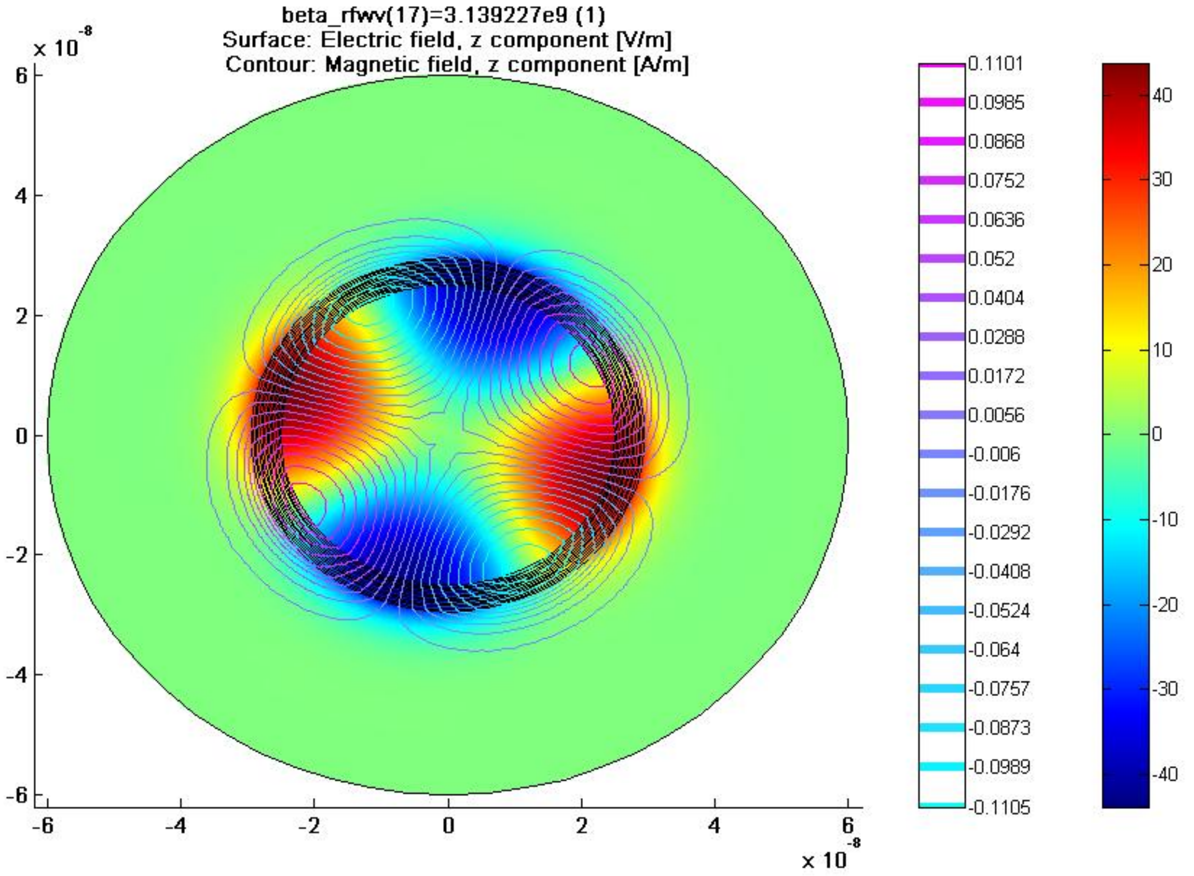
EM mode formed in a MWNT (7 walls) coated with gold



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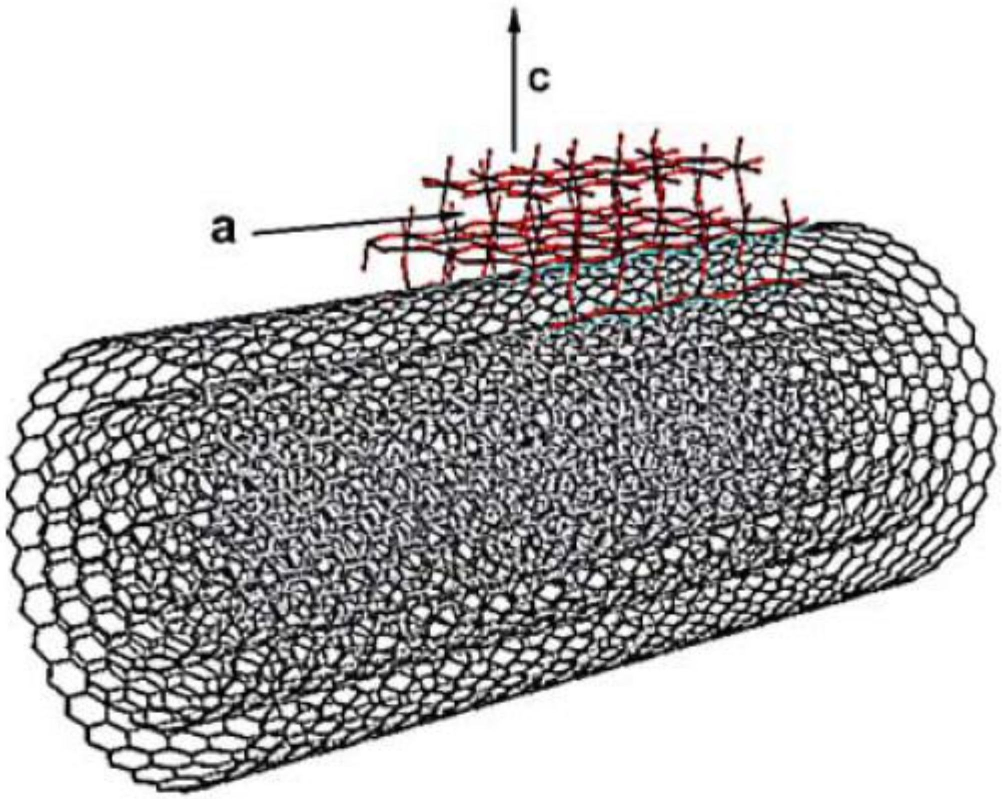
CNTs coated with WS_2



R.L.D Whitby, et. al., Appl. Phys. A **76,** 527 (2003)

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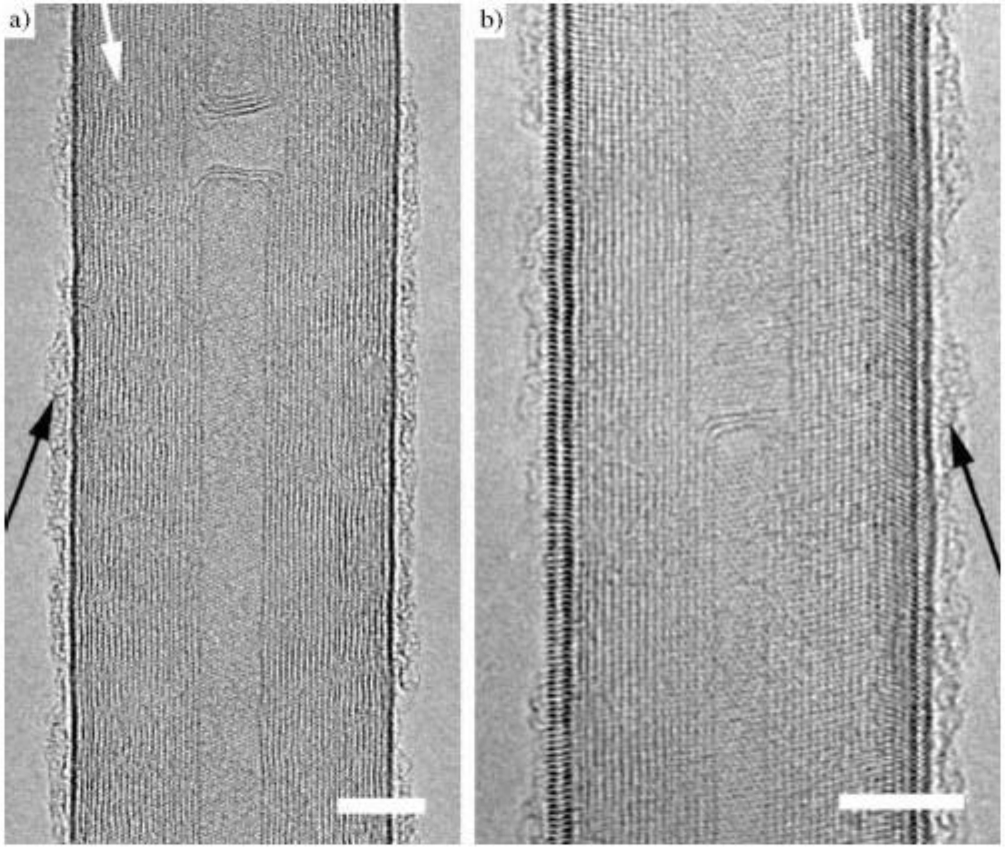
HRTEM images of a MWCN coated with a) single and b) double layer of $WS_{2.}$ Scale bars=5nm

(a)



(b)

R L D Whitby et. al., Chemphyschem (2001) No 10 p.620

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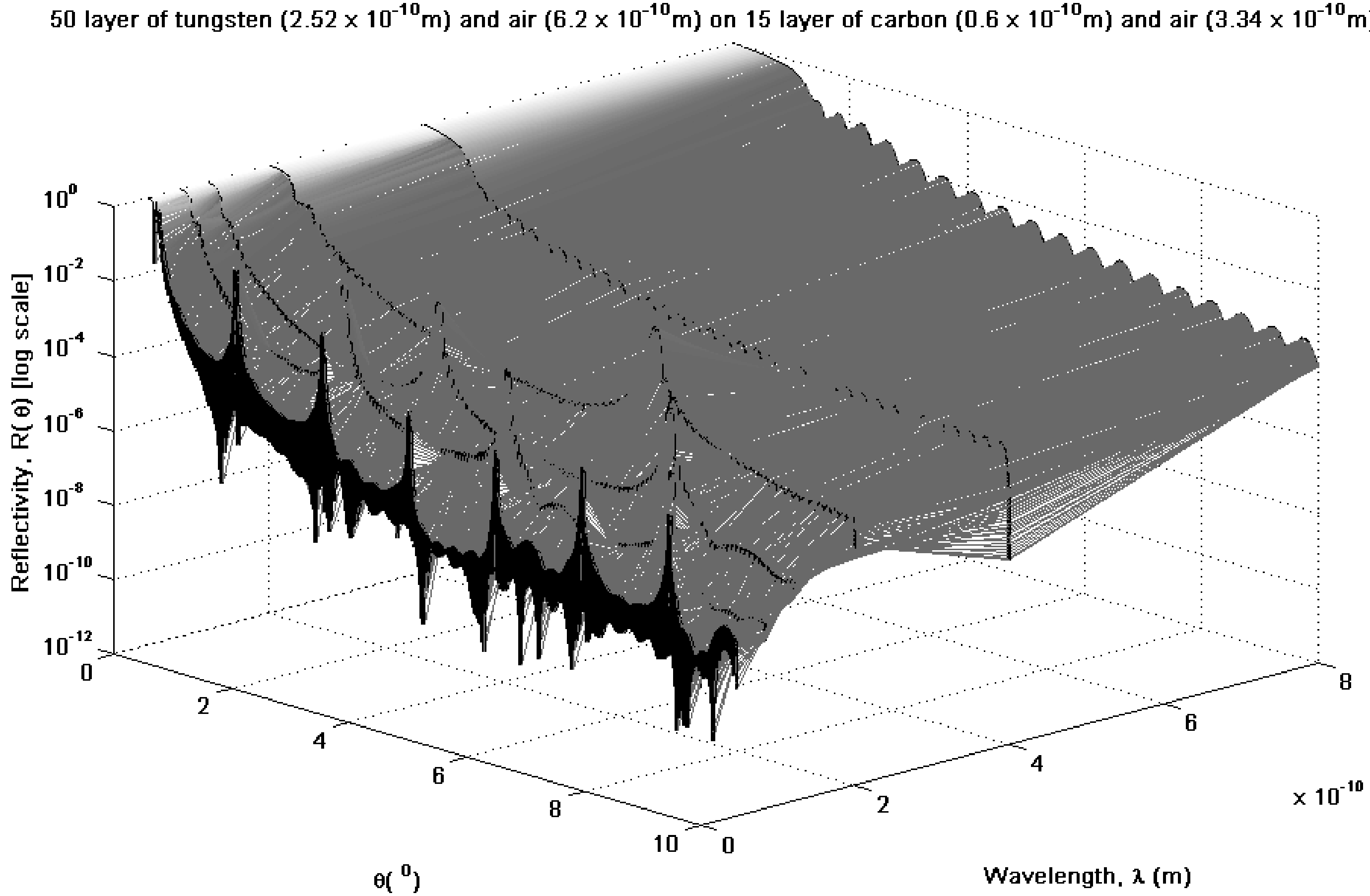
Reflectivity from 50 layers W/Air (2.52Å/6.2Å) on C/Air



Reflectivity with λ≈ 0.5Å and θ≈1.5° is about 6%

with λ≈ 2Å and θ≈6.5° is about 5%

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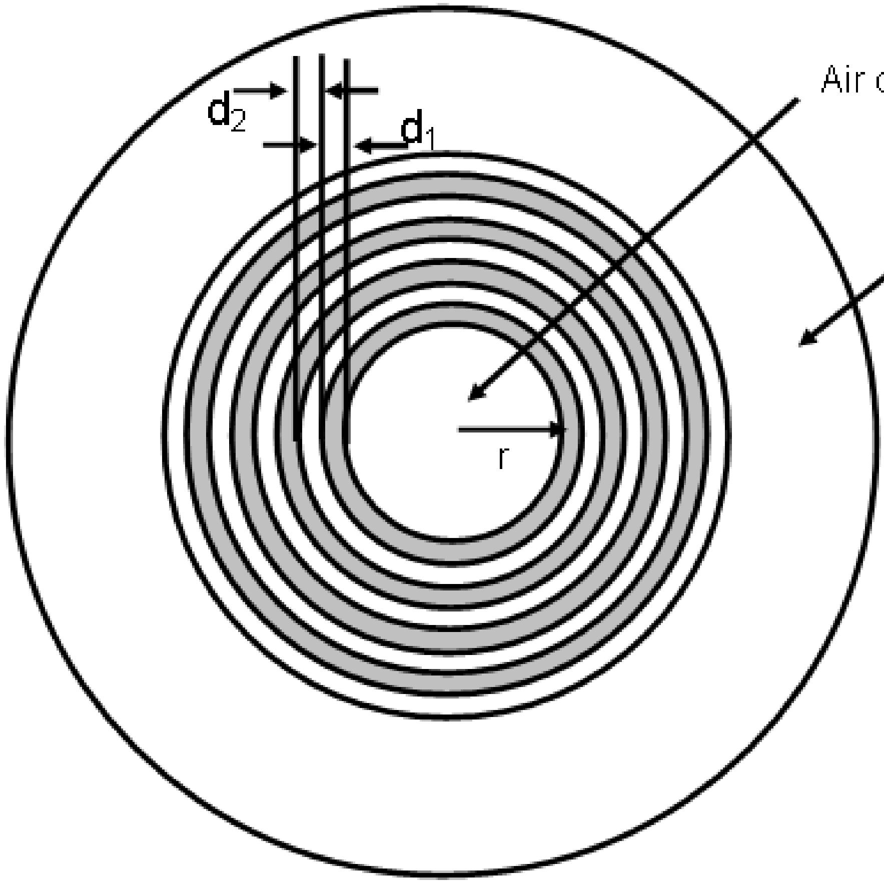
Structure of Bragg fibre



Scattering matrix theory developed by A. Yeh et. al.,
J. Opt. Soc. Am., **68** 1196 (1978)
Modified by Y Xu, et.al. J. Lightwave Technology, **20** 428 (2002)

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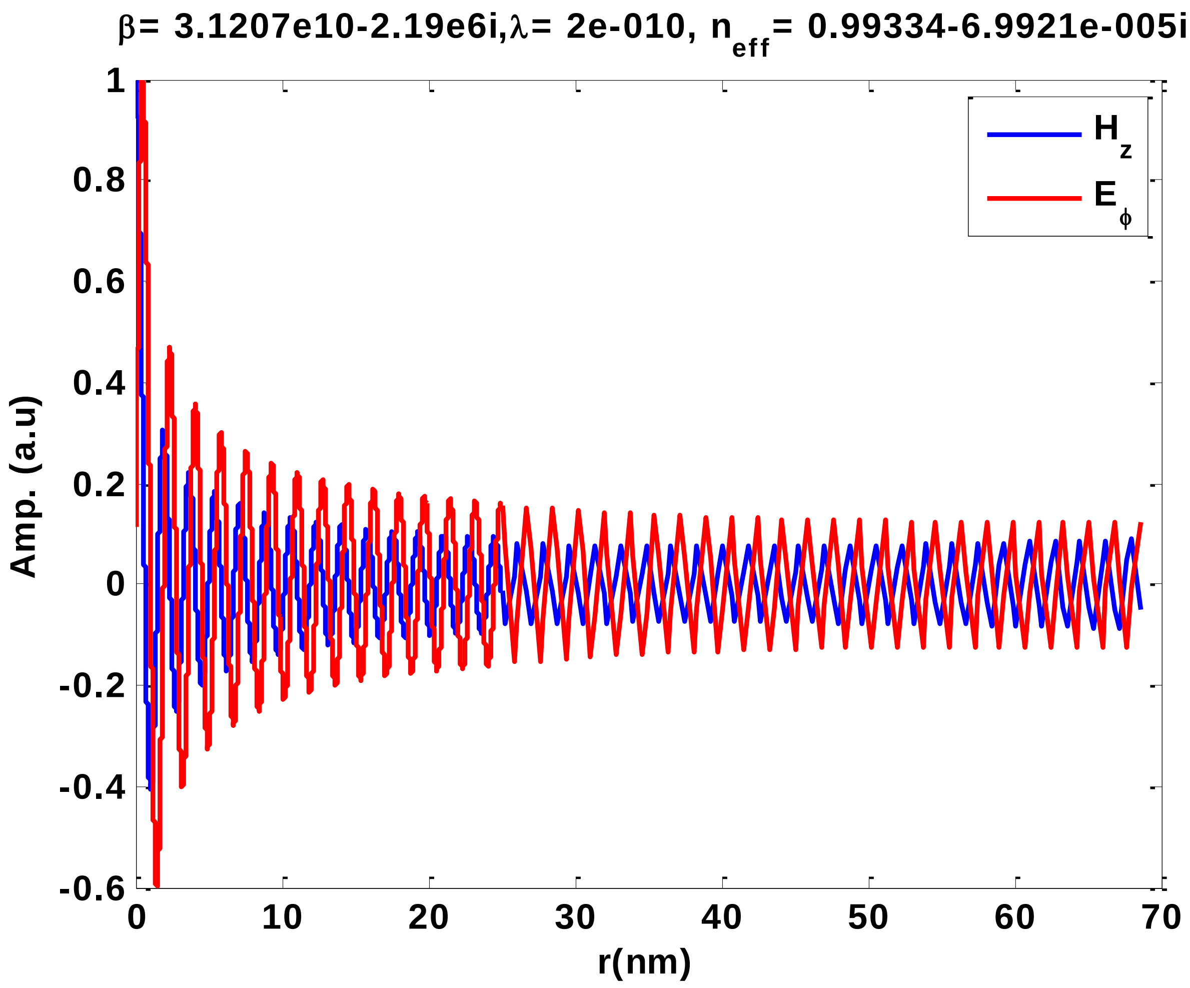
Radial component of the magnetic field, 50 nm radius nanotube coated with W/Air (2.52Å/6.2Å)



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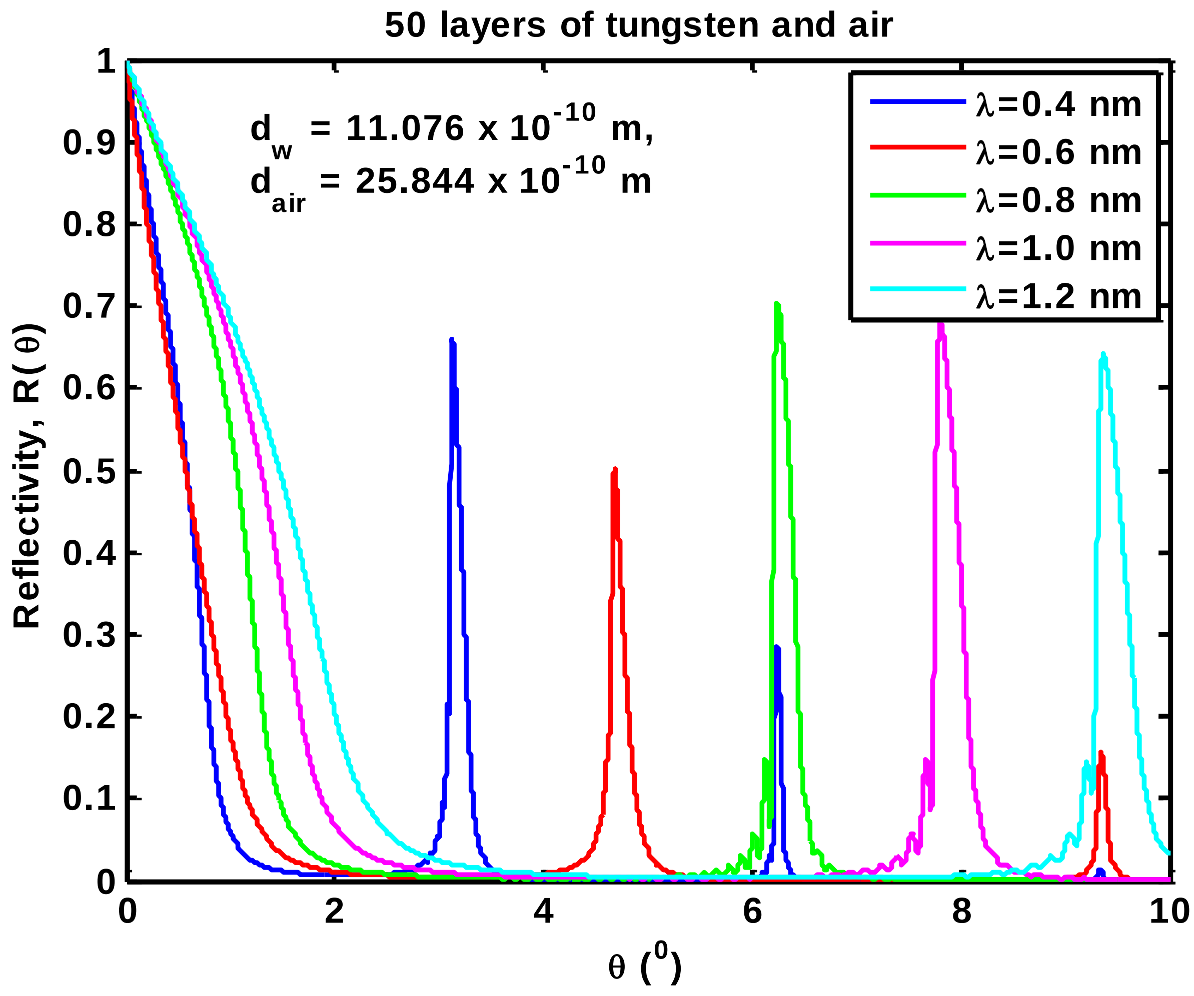
Reflectivity from 50 layers of W/Air (11.08Å/25.84Å)



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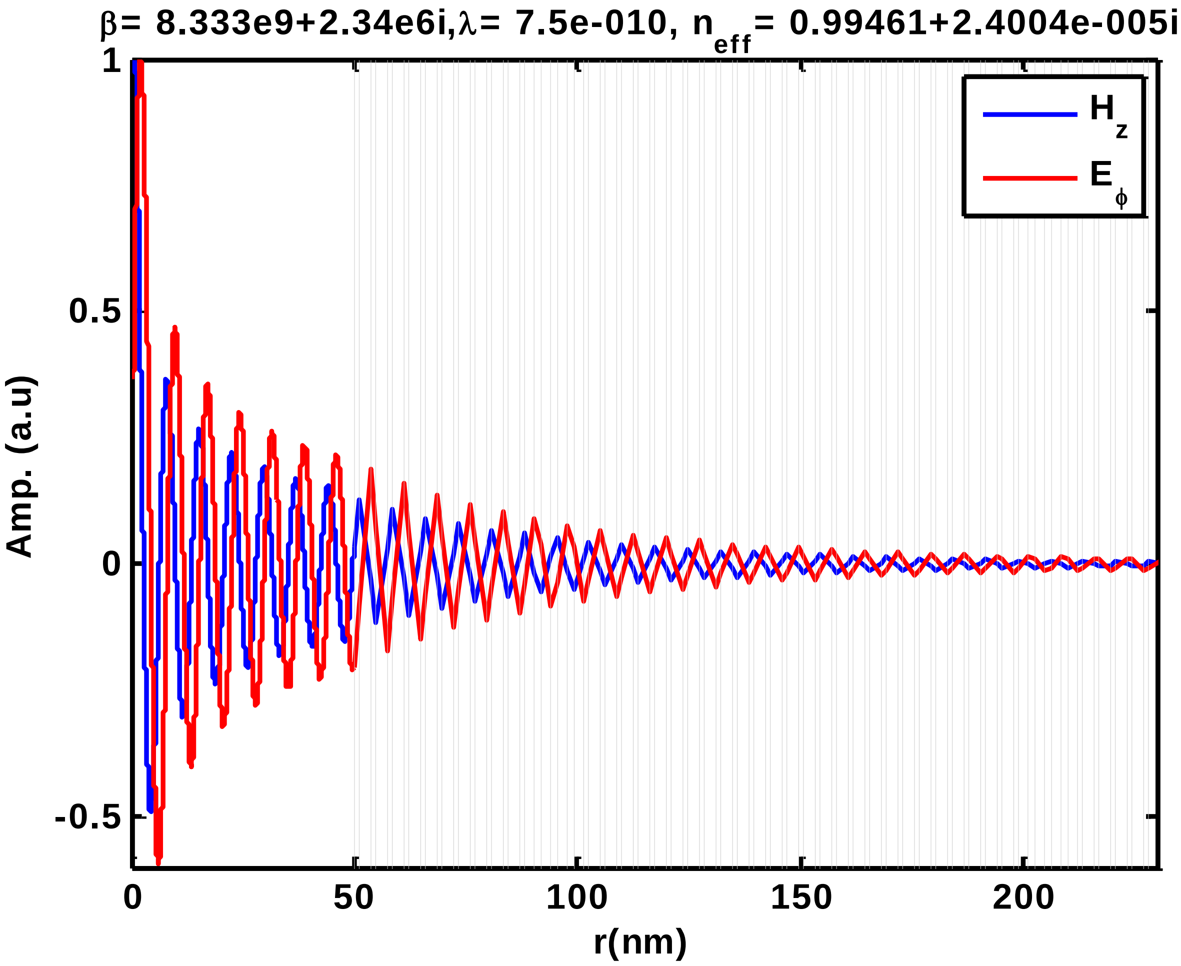
Radial component of magnetic field at a wavelength of 7.5Å for 50 layers of W/Air (11.08Å/25.84Å)



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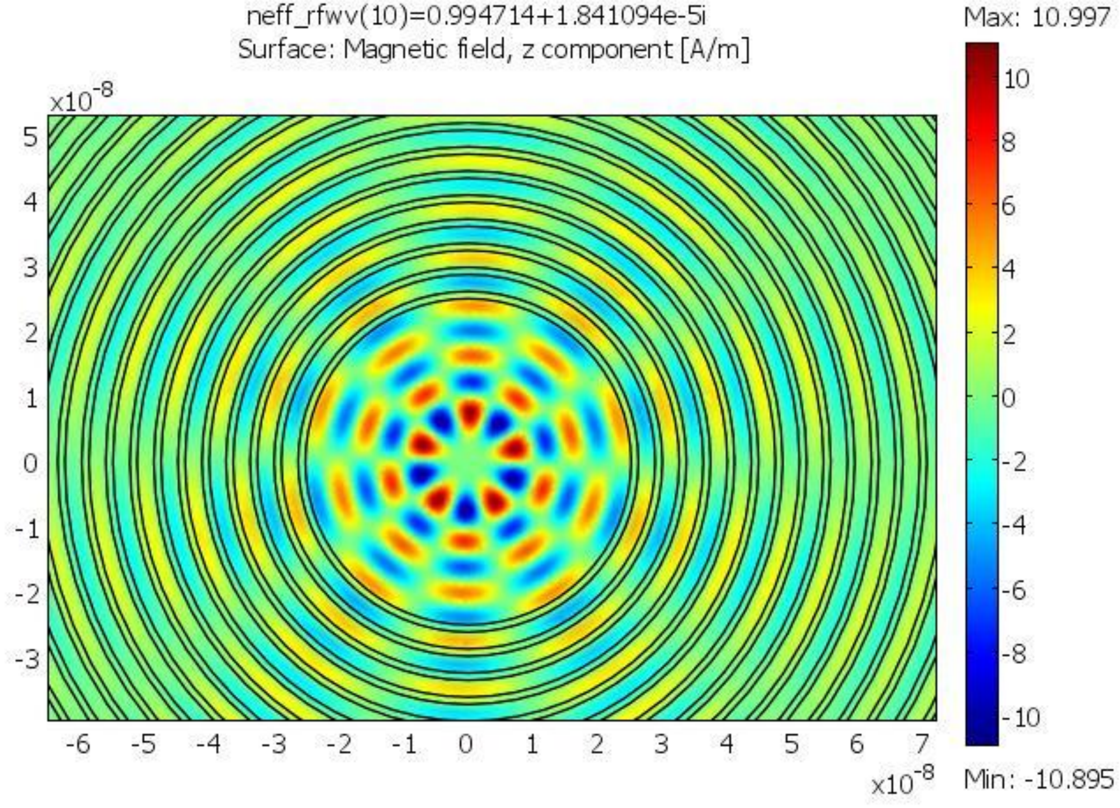
Modes established by Bragg scattering in MWNT coated with 50 layers of W/Air



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Conclusions

- Modelling suggests that x-ray propagation is feasible
- Multiwall CNTs have inherent Bragg structure but reflectivity is weak
- Coated CNTs offer potential as Bragg fibres but many layers required for strong reflectivity
- Need experimental verification of x-ray propagation

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