Face-centered cubic packing model for microwave properties of segregated structures

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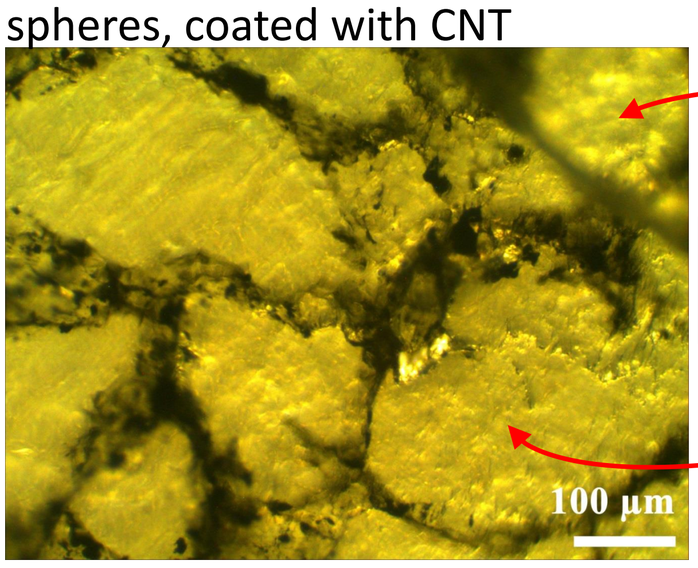
Purpose:

- to investigate the microwave absorption properties of the segregated structures
- To provide a model for microwave shielding of the segregated structures

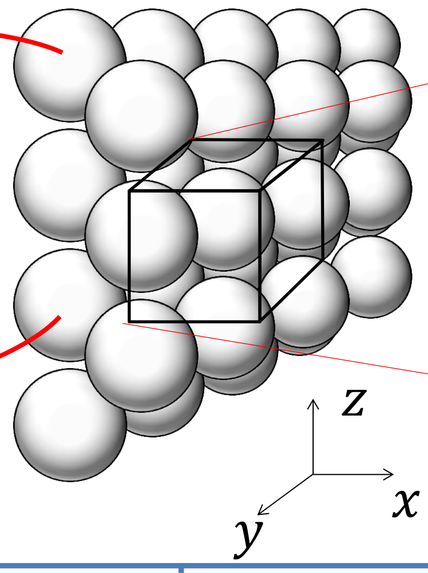
Object: Polymer spheres, coated with CNT, with CNT contents 0.5, 1.0, 1.5, 3.0 wt. %

Methods: S-parameter measurements using vector network analyzer N5227A, modeling of transmission, reflection, absorption indexes using Face-centered cubic packing model

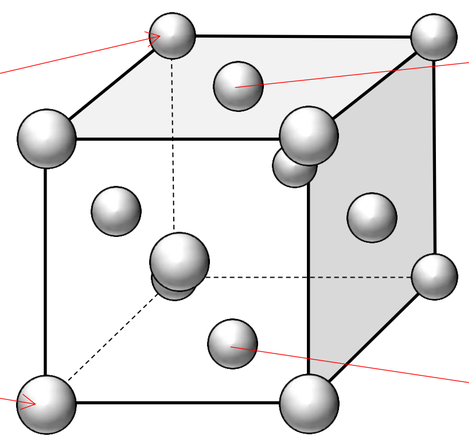
Optical image of polymer spheres, coated with CNT



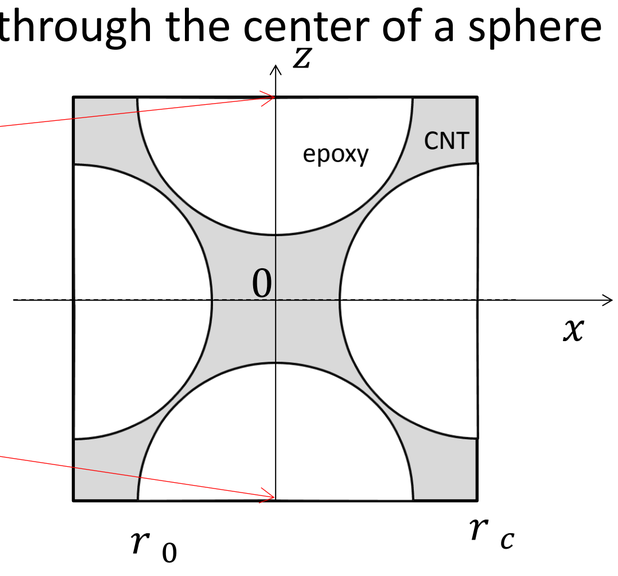
Face-centered cubic packing model of spheres arrangement



Unit cell



Unit cell xz cross-section through the center of a sphere



Shielding properties calculation

Refraction index in yz cross-section of the composite

$$n(f,x) = \frac{n_s(f)S_{yz}(x) + n_0(f)\left(4r_c^2 - S_{yz}(x)\right)}{4r_c^2}$$

$n_0(f) = \sqrt{1 - \frac{i\sigma}{2\pi f \varepsilon_0}}$ - compacted CNT refraction index

σ – conductivity of compacted CNTs

$n_s(f) \approx 2.9$ – polymer refraction index

yz cross-section of the polymer spheres:

$$S_{yz}(x) = \begin{cases} 2\pi(r_o^2 - x^2), & r_c/2 - |x| \le r_0 \\ 2\pi(r_o^2 - x^2), & |x| \le r_0 \\ 0, & |x| > r_0 \end{cases}$$

yz cross-section of the compacted CNT:

$$S_{CNT\ yz}(x) = 4r_c^2 - S(x)$$

To calculate the reflection index R and the transmission index T the unit cell is divided into N sublayers along x axis. The segregated structure sample of arbitrary thickness is then composed of N_0 layers of identical unit cells:

$$R = S_{11}^2 = \left(n_0 - \frac{C}{B}\right)^2 / \left(n_0 + \frac{C}{B}\right)^2$$

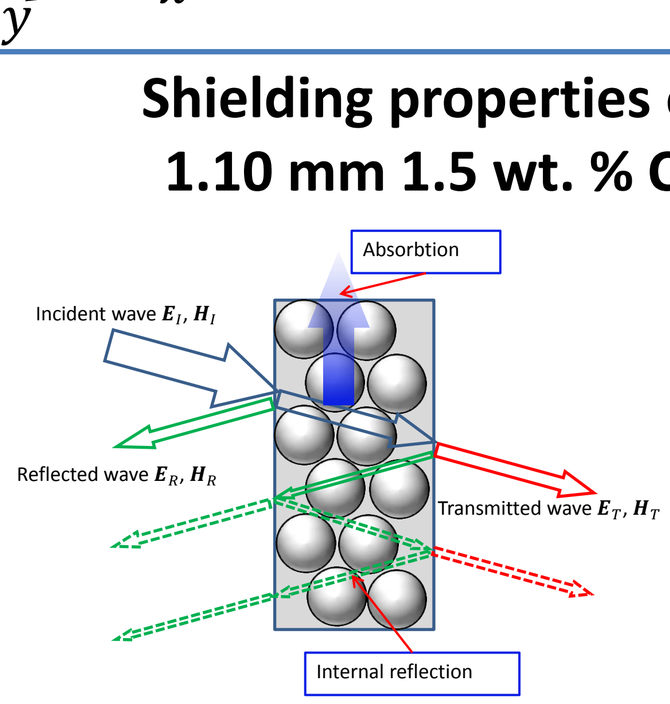
$$T = S_{21}^2 = 4n_0^2/(n_0 B + C)^2$$

$$\begin{bmatrix} B \\ C \end{bmatrix} = \left(\prod_{t=1}^{NN_0} \begin{bmatrix} \cos(k_t\tau) & isin(k_t\tau)k_0/k_t \\ isin(k_t\tau)k_t/k_0 & \cos(k_t\tau) \end{bmatrix}\right) \begin{bmatrix} 1 \\ n_e \end{bmatrix}$$

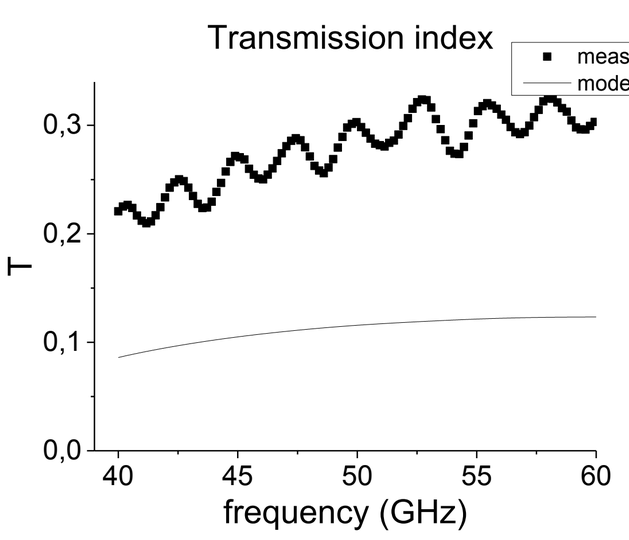
where $N_0 = d/r_c$ – number of layers in the whole structure, τ – thickness of a unit cell's sublayer

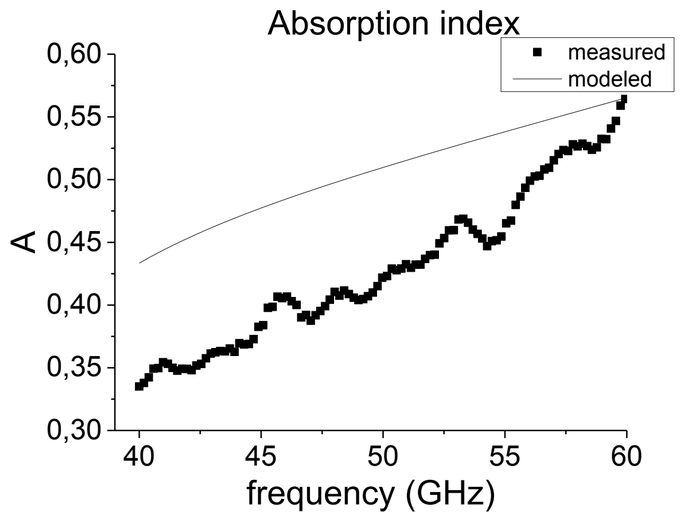
$k_t = \frac{2\pi}{\lambda a}\sqrt{n(x)^2 a^2 - \lambda^2/4}$, $k_0 = \frac{2\pi}{\lambda a}\sqrt{n_e{}^2 a^2 - \lambda^2/4}$ – wave vectors in a layer with refraction index $n(x)$ and in the air, $n_e \approx 1$, a – waveguide width, λ – wavelength

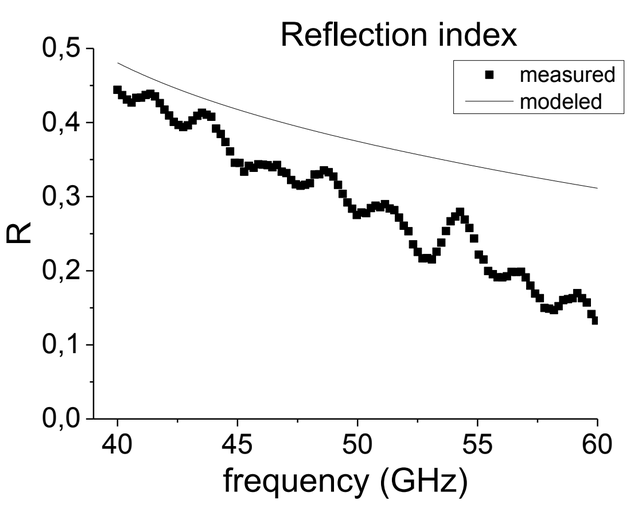
Shielding properties of segregated structure 1.10 mm 1.5 wt. % CNT + polymer spheres



$$\boldsymbol{T} = \frac{|\boldsymbol{E}_T|}{|\boldsymbol{E}_I|} \qquad \boldsymbol{R} = \frac{|\boldsymbol{E}_R|}{|\boldsymbol{E}_I|} \qquad A = 1 - R - T$$







Conclusions

- Face-centered cubic packing model has been implemented to calculate microwave reflection and transmission indexes of segregated structures.
- Comparison of measured and modeled transmission,reflection and absorption spectra of a 1.10 mm segregated structure 1.5 wt. % CNT + polymer spheres has shown satisfactory correlation.