Nanocomposites with carbon nanotubes used as tunable metamaterials

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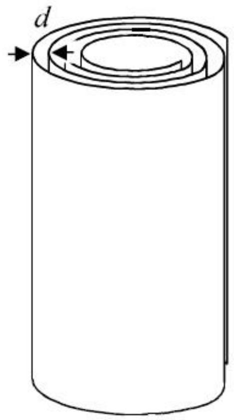
Nanomaterials

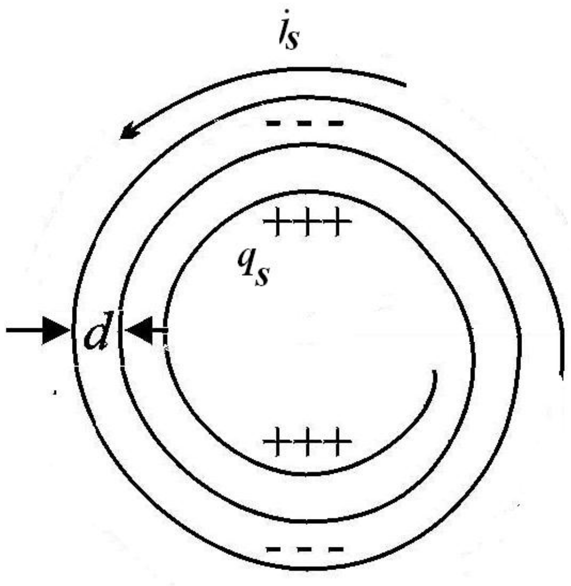
Introduced in 1999 by Rodger M. Walser: ***Macroscopic composites having a manmade, periodic cellular architecture designed to produce an optimized combination, not available in nature, of two or more responses to specific excitation.***

An adequate material to be used in the frequency range of 1MHz-500MHz is the **Swiss roll**, which can guide high frequency magnetic flux.

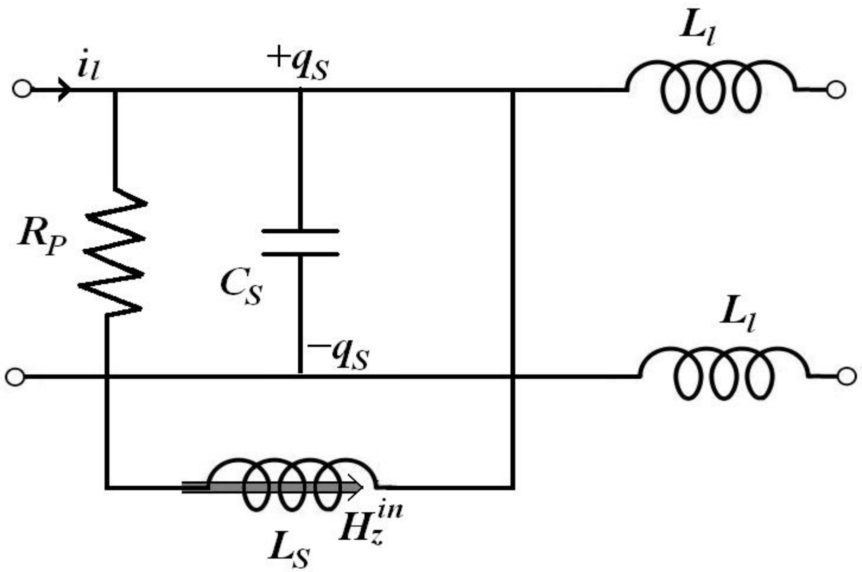
This *structure* has been proposed by *J.Pedry* and then realized by *M.C.K.Wiltshire*.

Swiss rolls





Induced current and charges



Equivalent circuit of a unit length

$$L_S = \mu_0 \pi r^2 (N-1)^2$$

$$C_S = \frac{\varepsilon_0 \varepsilon_r 2\pi r}{d(N-1)}$$

$$R_P = \frac{d(N-1)}{2\pi r} \rho_{diel}$$

$$\omega_0 = \frac{1}{\sqrt{L_S C_S}} = \sqrt{\frac{d c_0^2}{2\pi^2 r^3 (N-1) \varepsilon_r}}$$

$$Q = \frac{\omega_0}{\Delta\omega} = \frac{R_P}{\omega_0 L_S} = \frac{\rho_{diel}}{\eta_0} \sqrt{\frac{d\varepsilon_r}{2\pi r^3 (N-1)}}$$

The effective medium theory had been applied in the continuum approach, i.e. each phase is made from the particles embedded in host medium.

$$\varepsilon_0 \varepsilon_r \bar{E} = \sum_{i=1}^{N_P} f_i \varepsilon_0 \varepsilon_{r_i} \bar{E}_i$$

The field factor for the phase i^th^ $\Psi_i = \frac{\bar{E}_i}{\bar{E}}$

It can be write $\sum_{i=1}^{N_P} f_i \Psi_i \left(1 - \frac{\varepsilon_i}{\varepsilon} \right) = 0$

The field factor must be calculated or experimental measured.

More adequately is the using of probability density function for the aspect ratio, the type of distribution and its parameters depending on CNT used at nanocomposite. In these conditions, the field factor can be written

$$\Psi_i = \int_0^{1/2} \frac{P(B_i)\,dB_i}{1 + B_i\left(\dfrac{\varepsilon_{r_i}}{\varepsilon_{r_m}} - 1\right)}$$

where B_i is function of the aspect ratio, ε_{rm} is the relative permittivity of the polymeric matrix.

Nanocomposite CNT -PET

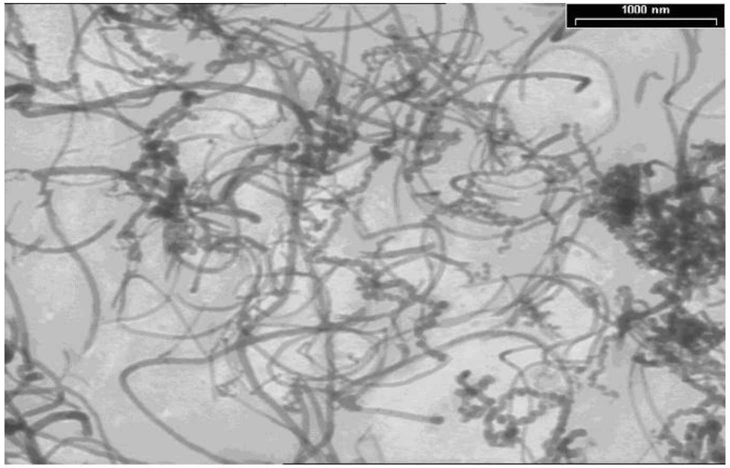
CNT - ENF 100 AA-GFE and HTF 110 FF_HHT

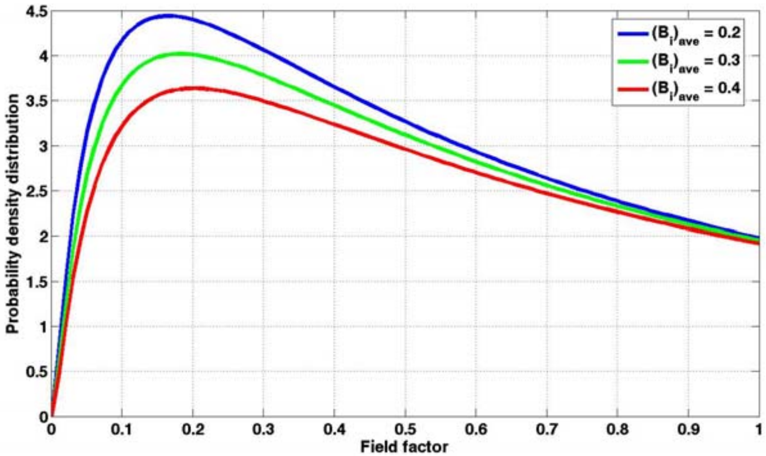
CNT were purified by air oxidation.

CNT were added to ODCB –phenol (1:1 by mass) and ultrasonicated (40 kHz, 100W) for 6 h to obtain uniformly dispersed CNT and then PET was added in. The mixture was stirred at 110^{0}C. After PET was dissolved, the solution was precipitated in extensive methanol.

- The nanocomposite was heated at 280^{0}C and laminated to obtain a band with 0.1 mm thickness. After lamination, the band was cut in strips with 50mm width.
- For realization of Swiss rolls structures, on the strip of nanocomposite was applied an Aluminum foil with 8μm thickness, the assembly being heated at 110^{0}C and relaminated.

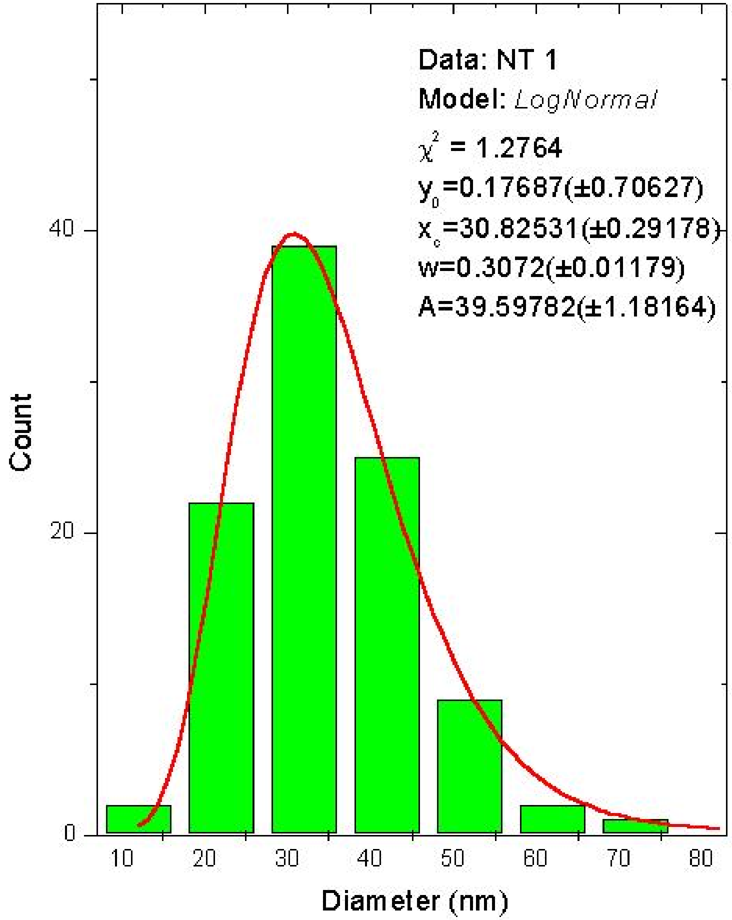
TEM image of CNT



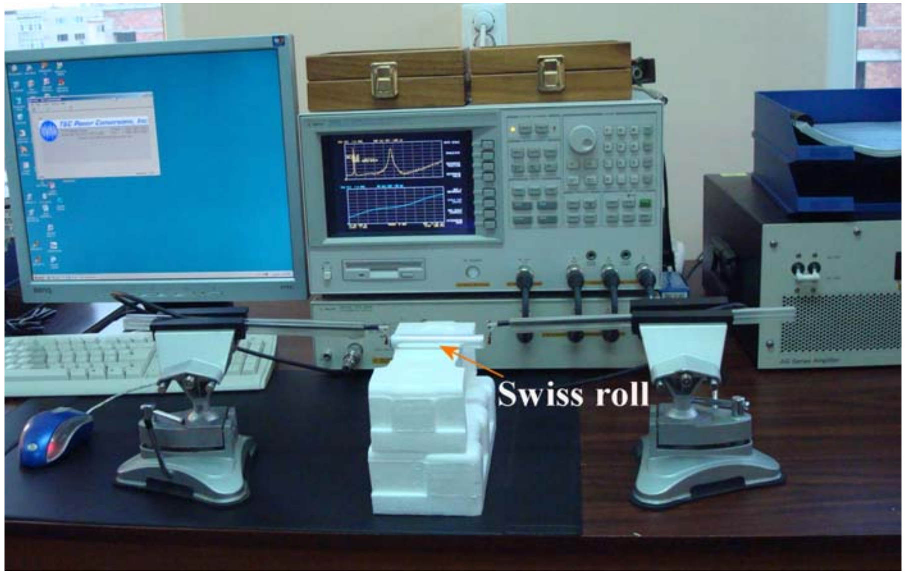


The probability density distribution vs. field factor for CNT type ENF 100 AA-GFE.

CNT diameter distribution for ENF 100 AA-GFE



Experimental set-up and results



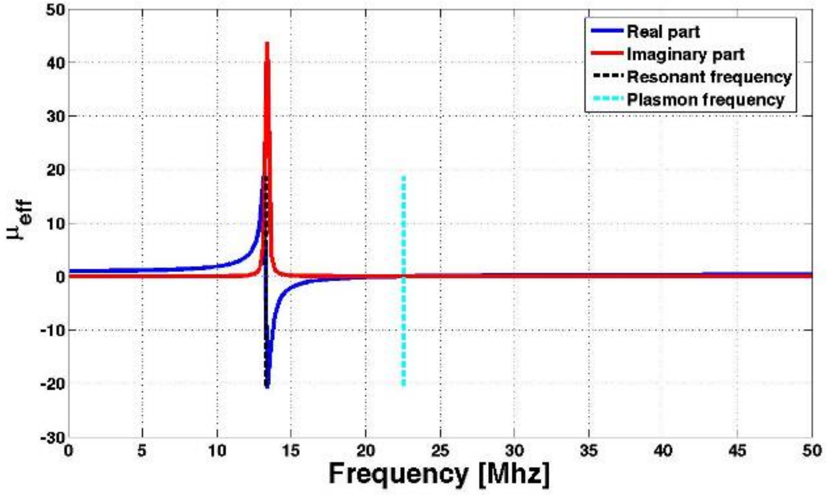
- Dielectric material test fixture 16453A for measurement of ε.
- S-parameter test set 87511A for determination of S parameters coupled at **Network / Spectrum / Impedance Analyzer 4395A Agilent USA,**

  - frequency 100kHz-500MHz
  - temperature $22^0C \pm 2^0C$.

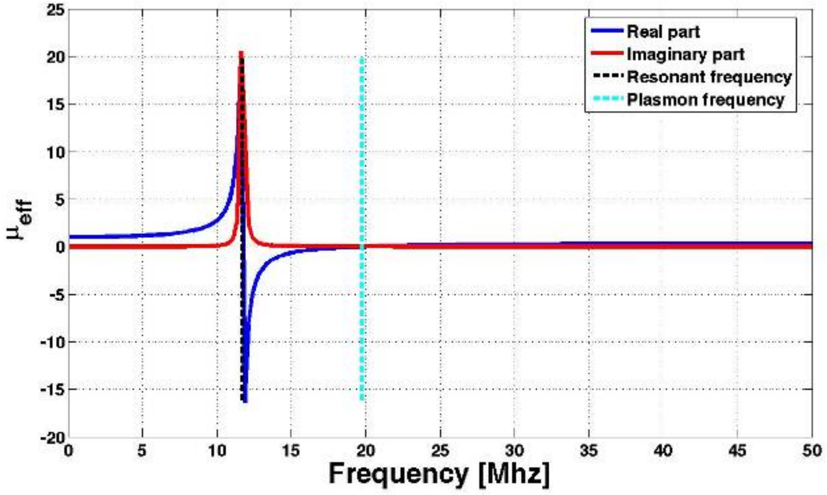
The electrical permittivity of CNT-PET composite

Sample	CNT type	Matrix	Volume fraction	$\sigma_{composite}$ measured [S/m]	$\varepsilon_{r_{composite}}$ Real part	
					Calculated with eq. (19)	Measured
A1	*ENF 100 AA-GFE.*	PET	0.32	0.15	2.4	2.7
A2	*ENF 100 AA-GFE.*	PET	0.64	0.19	3.5	3.8
A3	*ENF 100 AA-GFE.*	PET	0.91	0.22	7.8	8.2
B1	*HTF 110 FF-HNT*	PET	0.4	0.88	2.7	3.1

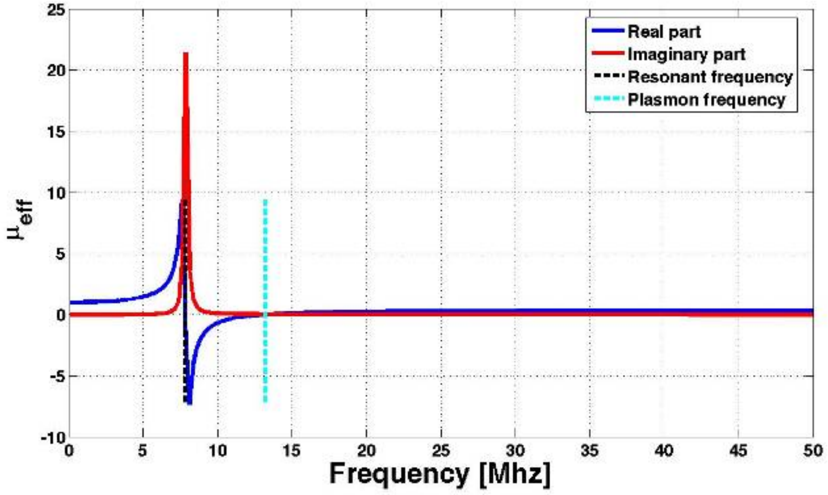
μ_{eff} vs frequency for Swiss roll structures



σ=0.15; ε_r=2.7



σ=0.19; ε_r=3.5



σ=0.22; ε_r=7.8

Conclusions

- A relative simple model for the prediction of electric permittivity (the real part) of nanocomposite CNT-PET type has been developed.
- Strips from this composite have been realized, the experimental measurements being in good concordance with the theoretical ones.
- The Nanocomposites CNT-PET have been used as dielectric in realization of Swiss rolls metamaterials and, due to the possibility of permittivity modification function on volume fraction of CNT, fine tuning of the complex structure of metamaterials can be made.