Nanocarbon electromagnetics in CNT-, GNR- and aerogel-based nanodevices: models and simulations

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Abstract
Electromagnetic properties of nanocarbon systems are essential for the creation of various nanoelectronic devices. Our major attention is focused on CNTs, graphene nanostructures (e.g., GNR and GNF), graphene-based aerogels (GBA) and CNT-based aerogels (CNTBA) as the basis for high-speed nanoelectronics and prospective nanosensors. Special attention is paid to fundamental properties of CNTs, GNRs and various CNT-­Me, GNR-­Me, CNT-­graphene interconnects. Nanosystems of 3D GBA and CNTBA are regarded as complicated systems made up of basic nanocarbon interconnected elements. Technological interest to contacts of CNTs or GNRs with other conducting elements in nanocircuits, FET-­type nanodevices, GBA and CNTBA is the reason to estimate various interconnect resistances, which depend on chirality effects in the interconnects. Simulations of electromagnetic properties in interconnects have been performed to evaluate integral resistances, capacitances and impedances of various topologies (1D, 2D and 3D) in nanodevices, including their frequency properties (GHz&THz).

Keywords: CNTs - carbon nanotubes, GNR – graphene nanoribbons, CBA – Carbon Based Aerogels, Carbon Nanoporous Materials, Carbon-based nanocomposites

I Introduction
The objective of the current study is to demonstrate the implementation of advanced simulation models to ensure a proper description of the electronic properties, electrical conductivity, electromagnetic and electromechanical phenomena of functionalized CNT-­ and GNR-­based nanostructures of different morphologies and their interconnects for nanosensor and nanomemory systems. The developed cluster approach based on the multiple scattering theory formalism as well as effective medium approximation is used for nanosized systems modeling supported by calculations of dispersion law, electronic density of states, conductivity, etc. [1]. The sensitivity of the local electronic density of states to external influences (mechanical, chemical, magnetic, etc) on the fundamental electromagnetic properties of CNTs, GNRs and their metal interconnects have been analyzed from the point of view of nanosensor applications [1, 2]. We develop a set of prospective models of nanocarbon-­based nanomaterials and nanodevices based on various interconnects and interfaces (see Figure 1).

Correlations between multiple external influences (mechanical, chemical, electromagnetic etc factors) and fundamental properties of nanocarbon materials are studied.

2 Nanodevices for effective electron transport
We have developed structural models for CNT-­Me and GNR-­Me junctions, based on their precise atomistic structures, which take into account the chirality effect and its influence on the interconnect resistance for Me (= Fe, Ni, Cu, Ag, Pd, Pt, Au) with the predefined CNT (or GNR) geometry. In the simplest cases, the electronic structure of CNT-­Ni interconnects can be evaluated through the DOS for a C-­Metal contact considered as a ‘disordered alloy’ [1].

In the current study, we have developed more complicated structural models of CNT-­metal junctions based on a precise description of their atomistic structures. When estimating the resistance of a junction between a nanotube and a substrate, the main problem is caused by the influence of the nanotube chirality on the resistance of SW and MW CNT-­Me interconnects (Me = Fe, Ni, Cu, Ag, Pd, Pt, Au), with a predefined CNT geometry [2-­3].
2.1. CONDUCTIVITY AS AN IDENTIFYING TOOL OF NANOSENSOR SYSTEMS

Usually two basic electron conductivity mechanisms are considered in CNT-based structures. The ballistic mechanism is engaged in electron transport within CNTs, while the collisional mechanism is characteristic of CNT-substrate interconnects [4]. Hence the general conductivity $\sigma_{\text{gen}}$ is evaluated as follows:

$$\frac{1}{\sigma_{\text{gen}}} = \frac{1}{\sigma_{\text{coll}}} + \frac{1}{\sigma_{\text{ball}}}.$$  \hspace{1cm} (1)

For pure CNTs, we clearly observe that $\sigma_{\text{ball}} \gg \sigma_{\text{coll}}$. The collisional contribution is basically connected with the specific morphology of the interconnect space. In the framework of multiple scattering theory formulation and effective medium approximation, we can evaluate both factors of conductivity. A special question for modelling is the dependence of both conductivity mechanisms on the electron free path length, which, in the case of pure CNT, is usually considered as the nanotube length.

The analysis of Kubo-Greenwood conditions in relation to CNT and GNR morphologies has been presented taking into account $dc$ ($\omega = 0$), $ac$ ($\omega \neq 0$) regimes and the temperature factor of the electron transport.

The calculations of conductivity are usually performed using Kubo-Greenwood formula [1, 2]:

$$\sigma_{\text{ac}}(\omega) = \frac{e^2}{4\hbar} \int \left[ f(E) - f(E + \hbar \omega) \right] \rho(E) \rho(E + \hbar \omega) dE,$$  \hspace{1cm} (2)

where $\omega$ is a real frequency parameter of Fourier transform for the time-dependent functions, $f(E)$ is Fermi-Dirac distribution function, $D_{E,E'} = \int \Psi^*_{E'} \Psi_E d\mathbf{r}$, where $\Psi_{E,K}$ is a complex wave vector of the effective medium. The dispersion function $E(K)$ determines the properties of the wave function $\Psi_{E,K}$ upon the isoenergy surface in $\mathbf{K}$-space.

However, Kubo-Greenwood formalism is free from this division on ballistic and collisional mechanisms and seems to be more objective. The analysis of Kubo-Greenwood’s conditions in respect of CNT morphology has been presented taking into account both $dc$ ($\omega = 0$) and $ac$ ($\omega \neq 0$) regimes as well as the temperature factor of electron transport [5, 6].
calculations of conductivities based on the EDOS results have been made for graphene-based materials [9,10] (see Figures 3 and 4).

3 CNT interconnects magnetic phenomena and magnetically simulated CNT growth in CVD processes

There is a relation between the use of magnetic catalysts and the CVD growth of CNTs determining the most commonly used materials for the CNT growth - Fe, Co and Ni. Nanoparticles of the latter catalysts are magnetically isotropic. It is possible to use magnetically anisotropic nanoparticles such as those in the alloys with a different substitutional disorder (e.g., Fe–Pt–x–y) to manage the CVD process with the formation of the predefined CNT chiralities. Limitations in the control after the parameters of CNTs growth are discussed. The role of the number of effective bonds inside interconnects and the discrete character of chiral indeces have been studied in relation to the expected qualities of CNT output in the CVD process. Moreover, it is a way to create effective magnetic nanomemory, where a CNT ‘forest’ provides communication with other parts in novel integrated nanodevices by means of spin waves transport.

Nanocarbon-magnetic metal interfaces open new possibilities for the creation of nanospintronics devices, e.g., nanomemory devices. The model of CNTs growth with the predefined chiralities in a magnetically managed CVD process with the use of magnetically anisotropic Fe–Pt–x nanomaterials with various substitutional disorders has been developed. The model and magnetically controlled conditions, stimulating the CNT growth in a CVD process, aim at the predictable SWCNT diameter and chirality. The perfect picture of the magnetically stimulated CVD process for CNTs growth can be presented as a CNT forest (see Figure 5). Such a system of nanotubes can also be considered as a prototype of the magnetic memory, where ferromagnetic nanoparticles serve as cells of the magnetic memory – that is, ferromagnetic contacts are controlled by spin pulses, the transport of which is provided by nanotubes.

At the same time, the growth control over chiral and non-chiral nanotubes essentially depends on stoichiometric composition of Pt–Fe nanoparticles. The beginning of the nucleation process providing the growth of nanotubes might be connected with stochastic fluctuations of the magnetic moment in a carbon atom relative to the direction of the local magnetic field in a nanoparticle.

Distribution of the fluctuation angle obeys the Gaussian law:

$$f(\theta) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(\theta - \theta_0)^2}{2\sigma^2}\right), \quad (3)$$

where $\sigma^2$ is the angular dispersion of thermal fluctuations of the magnetic moment angle of a carbon atom. To evaluate this dispersion, the potential energy change of the magnetic moment under the influence of the thermal energy should be evaluated: $\mu_T B(1 - \cos\theta_\parallel) \approx k_B T_{\text{CVD}}$, where $\mu_c$ is the induced magnetic moment of a carbon atom $\mu_c = 1.25 \mu_B$ (see evaluations in [65]), $\mu_B = 5.788 \cdot 10^{-5} \text{eV/T}$, $B$ is the magnetic induction of the catalyst surface, $\theta_\parallel = \theta - \theta_0$ is the operating temperature of the CVD process, $k_B = 8.617 \cdot 3324(78) \cdot 10^{-5} \text{eVK}$ is the Boltzmann constant.

Hence $2\sin^2\frac{\theta_\parallel}{2} \approx \frac{k_B T_{\text{CVD}}}{\mu_c B}$, Taking into consideration one of the main problems of the nanotubes growth control – the chirality control – it is necessary to look for the minimal fluctuation angle $\theta_\parallel$. 
Then $\sigma^2 = \theta^2 = \frac{2k_B T_{\text{CVD}}}{\mu_c B}$.

The condition of the small fluctuation angle (e.g., <10°) at certain temperature of the CVD process imposes limitations on the values of the demanded magnetic induction $B$. Taking into account the ratio between the chirality angle and the direction of the magnetic field $\phi = \theta_{\text{B}}$, Figure 13 displays the predictable scattering of chiralities for nanotubes of approximately the same diameter.

We are also able to evaluate the necessary value of the magnetic field $B$ providing the expected chirality angles scattering, e.g. $\sigma = 0.2$ (approximately 12°) leads to the $B$ evaluation for the CVD process temperature $T_{\text{CVD}} = 700^\circ C$ as $B = \frac{2k_B T_{\text{CVD}}}{\sigma^2 \mu_c} \approx 16755 \approx 57895 \approx 6 \cdot 10^4 T$. For small angle dispersions $\sigma^2 = \theta^2 = \frac{2k_B T_{\text{CVD}}}{\mu_c B}$, the high local magnetic field on the nanoparticle surface is necessary. The result also strongly depends on the carbon atom magnetic moment $\mu_c$ [4] (see also Figure 6).

Taking into account the possible errors in diameters of the growing nanotubes, their evaluation from beneath is defined by the minimal variations in parameters of the chirality vector $\vec{c} = (n, m) \Delta n t$ and $\Delta m$, which equal 1.

Considering the formula for calculating the diameter of CNT:

$$d = \frac{\sqrt{3}a}{\pi} \sqrt{n^2 + n^2 + mn} \text{, where } a = 0.142 \text{ nm is the distance between the neighboring carbon atoms in the graphite plane.}$$

The relationship between chirality indices $(n$ and $m$) and the angle $\phi$ is presented by the ratio:

$$\sin \phi = \frac{m\sqrt{3}}{2\sqrt{n^2 + n^2 + mn}}.$$
of two ferromagnetic metals separated by a thin spacer layer of normal metal (see e.g. Figure 2) or semiconductor. They are called spin-valves and are used as magnetic field sensors. The resistance of the device is dependent on the relative magnetization orientation of the ferromagnets. It is \( R_p \) when the magnetizations are parallel and \( R_A \) when they are antiparallel. The GMR ratio is defined as \( \text{GMR} = \frac{R_A - R_p}{R_p} \) as well as for TMR is \( \text{TNR} = \frac{R_A - R_p}{R_p} \) (Moodera, 1995). It was first in 1995 when room temperature TMR was discovered by Jullière [2] and caused a great interest in spintronics after GMR was discovered in 1988 (Baibich et al [3]). Our idea is that the same effect can be reached by introducing metal or semiconductor-like CNTs into the N space. The TMR signal operates in the same way as the GMR, where \( R_p \) and \( R_A \) are the resistances of the device for parallel and antiparallel orientations respectively of the ferromagnets magnetization.

The sign and size of the interlayer exchange coupling is dependent on the thickness of the nonmagnetic spacer. The coupling can thus be ferromagnetic and antiferromagnetic dependent on the spacer thickness.

The device shown in Figure 7 is the so-called current perpendicular to the plane (CPP, Figure 7a) geometry. The resistance of such geometry is very low and difficult to detect. For practical applications, structures with the current in the plane (CIP, Figure 7b) are used because they have higher resistance and thus higher difference with the magnetic field.

4 Nanoporous and nanocomposite material models

Nanoporous systems are considered as complicated ensembles of basic nanocarbon interconnected elements (e.g., CNTs or GNRs with possible defects and dangling boundary bonds) within the effective media type environment (Figures 1a, 1b, 1c). Interconnects are essentially local quantum objects and are evaluated in the framework of the developed cluster approach based on the multiple scattering theory formalism as well as effective medium approximation [1,2]. Particular properties of carbon-based nanoporous systems in dependence on the porosity extent, morphology and fractal dimension are practically studied to find useful correlations between their mechanical and electrical properties.

In cases when nanocarbon clusters are embedded in high resistance media (instead of vacuum) we come to the model of nanocomposite material. Now we pay attention to the model of nanocomposite materials based on carbon nanocluster suspensions (CNTs and GNRs) in dielectric polymer environments (e.g., epoxy resins) is considered as a disordered system of fragments of nanocarbon inclusions with different morphology (chirality and geometry) in relation to a high electrical conductivity in a continuous dielectric environment. Presumably, the electrical conductivity of nanocomposite material will depend on the concentration of nanocarbon inclusions (in fact, carbon macromolecules). Isolated nanocarbon inclusions will provide conductivity due to the hopping conductivity mechanism through dangling bonds up to the percolation threshold, when at high concentrations (some mass %) a sustainable ballistic regime appears, which is characteristic of pure carbon systems.

Considering the Kubo-Greenwood relationship for small quasimomentary potential energy for large distances is proportional to \( \exp(-\alpha R) \), where \( \alpha - a^{-1} \), \( a \) is the characteristic ‘Bohr-like’ radius. The interaction between the electronic states localized at points \( \mathbf{R}_i \) and \( \mathbf{R}_j \) describes the overlapping integral:

\[
I = \int \psi_j^*(\mathbf{r} - \mathbf{R}_j)\psi_i(\mathbf{r} - \mathbf{R}_i) d^3 r \exp\left(-\left|\mathbf{R}_i - \mathbf{R}_j\right|/a\right).
\]

If two states are divided by a distance \( R \), then \( D \) can be approximated: \( D = \frac{m_0 R}{\hbar} \exp(-\alpha R)(\alpha a)^{3/2} \).

If two centres are close and wave functions are in resonance: \( D = \frac{m_0 R}{2\hbar}(\alpha a)^{3/2} \).
Following to Mott [13] we can see:

\[ \sigma(\omega) = \frac{n_e^2}{2\hbar} \left\{ \rho(E_f) \right\}^2 (\hbar \omega)^3 a R_0^4, \]

where

\[ R_0 = \frac{1}{\alpha} \ln \left( \frac{2 I_0}{\hbar \omega} \right), \]

when e.g., \( I_0 = \frac{e^2}{\alpha} \left[ \frac{3}{2} (1 + \alpha R) + \frac{1}{6} (\alpha R)^3 \right] \) is the amplitude of overlapping integral for hydrogen-type wave functions.

When the centers are strongly separated from each other, the overlap integral is very small, but strictly speaking, it never turns into zero.

However, in the material, which is considered an insulator, it is easy to detect very small currents due to tunneling of electrons from site to site, possible because of this overlap of the wave functions. Actually implemented mechanisms of electron hopping throughout "islands" of conductivity (nanocarbon clusters) is very complex.

However, we should accept that the probability of electron transition from the center point \( \mathbf{R}_1 \) to the center point \( \mathbf{R}_2 \) is proportional to the quadrat of overlapping integral: \( P \propto \exp(-2|\mathbf{R}_1 - \mathbf{R}_2|/a) \).

A macroscopic conductivity can be estimated as:

\[ \sigma = \exp(-4\alpha R/a). \]

The constant \( \alpha \) is evaluated as 0.70. This is approved by Monte-Carlo numerical simulations [14]. Only the most favourable ways for the electron hopping i.e. some of their share \( \xi \) should be taken into account. Evaluation of conductivity in this case is modified by:

\[ \sigma(\xi) = \exp(-4\alpha \xi^{-1/3} R/a - \frac{1}{3} \xi W / kT). \]

The most precise averaged evaluation of the overall conductivity of the system [15], which is regulated by the hopping of electron between ‘nanocarbon macromolecules’, then will be: \( \sigma_{\text{NC}} = \sigma_0 \exp(-4\frac{4\alpha r_{\text{IC}}}{a})^\frac{3}{4} \left(\frac{W_0}{kT}\right)^\frac{1}{4}, \)

where \( r_{\text{IC}} \) - is the length of the tunnel ‘jump’ of the electron equal to the distance between ‘nanocarbon’ clusters, \( \sigma_0 \) is the normalization constant which means the conductivity of monolithic dielectric medium.

If we introduce the volume part as an indicator of the nanocarbon inclusions concentration: \( \eta = \left( \frac{R_0}{R_0 + R} \right)^3 \),

where \( R_0 \) is the average nanocarbon macromolecule radius, \( R \) is, as earlier, the width of potential barrier between the nearest nanoclusters which is responsible for percolation ability of the model nanocomposite. We should also diminish the hopping phenomena and percolation probability taking into account the nanocarbon macromolecule orientation within a hypothetical sphere embedded into high resistance dielectric medium.

On the basis of this definition we can obtain a contribution of potential nanocarbon interconnects to nanocomposite conductivity as follows (see also Figure 8):

\[ \ln \left( \frac{\sigma_{\text{NC}}}{\sigma_0} \right) = -\frac{4}{3} \frac{4\alpha}{a} R_0 (\eta^{-1/3} - 1)^{1/3} \left(\frac{W}{kT}\right)^{1/4}. \]

Added to this is the effect of intrinsic nanocarbon cluster conductivity, which is dependent on its morphology. The electric conductivity will also depend on the spatial orientation of nanocarbon inclusions. It will be greater for the longitudinal electric field orientations and lower for the transverse ones.

Of course, any spatial orientations are technologically possible. The overall conductivity of nanocomposite material is; \( \Sigma = \Sigma_0 + \sum_{k=1}^{M} R_k, \) where

\[ \Sigma = \Sigma_0 + \sum_{k=1}^{M} R_k, \]

\[ \Sigma_0 = \left( \frac{R_0}{R_0 + R} \right)^3. \]

A natural application of this kind of nanocomposite materials is nanosensors of pressure and temperature.
5 Instead of conclusion. CNNTBA and GBA electromechanical properties

Talking about porous materials in general and, in particular, about nanocarbon-based systems such as CNNTBA and GBA, we meet new complications for Solid state theory. We lose a strong dimension, regularity and continuity. In some sense, porous materials are 'pure' surfaces. We should also control the fractal dimention of porous materials as a key parameter of their morphology. A porous material in certain cases present a mixture where one component is a substance (for example – a metal) and the other - emptiness. To describe the properties of porous bodies, the percolation theory can be used.

One important difference: the system can not exist as finite metal clusters, since they cannot hang in a vacuum. Consequently, the metal component is always connected - all metals belong to the infinite cluster.

In a conventional two-component mixture two percolation transitions occur at different values of x, corresponding to the formation of an infinite cluster for each of the two components.

These properties are largely similar to the properties of gels. Unique mechanical and electrical properties of CNNTBA and GBA make these nanomaterials prospective candidates for new types of nanodevices and nanosensors. The model of electromechanical correlations has been developed based on the fractal dimension induced by the changes of the aerogel structure. Mechanical stresses or gas inclusions can modify the morphology of CNNTBA and GBA changing the resistance. Thus, the resistance is considered as a function of fractal dimension, \( R \propto \omega f(\frac{d_s}{d}) \), where \( \omega \) is the frequency, \( f(\frac{d_s}{d}) \) is the function of fractal dimension \( d_s \). This fractal property of CNNTBA and GBA structures provides the possibility of creating mechanical nanosensors.

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References


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