On behalf of the Organizing Committee it is our pleasure to welcome you to Minsk, for the NATO Advanced Research Workshop on “Fundamental and Applied NanoElectroMagnetics”, FANEM 2015.

Ongoing rapid progress in the synthesis of different nanostructures and their fascinating physical and chemical properties not associated with bulk materials, have motivated a significant and potentially long-lasting increase of human resources and financial investments into the nanotechnology field all over the world. No other area of materials research combines the exciting progress in fundamental research with the immediate promise of its realization in new devices & products that have both high societal impact and high commercial potential. The potential of nano-sized elements and nano-structured materials for electromagnetic fields manipulation and processing motivates the born of a new research discipline – Nanoelectromagnetics

In our wishes, this meeting aims to provide a forum for scientists and technologists specializing in different areas of the nanoparticles and nanostructured materials synthesis and applications to interact with their counterparts working in the areas of electromagnetic theory and applied electromagnetics.

The technical program of FANEM is organized in 9 technical sessions (8 oral and 1 poster session), touching a wide variety of topics, including general theory, modeling, design, synthesis, characterization and applications, ranging from commercial thin-film coatings to metamaterials and to circuit components and nanodevices.

We wish to thank all the people and the institutions that made possible this event, starting from the NATO, that has sponsored the workshop under its Science for Peace and Security Program, the Institute for Nuclear Problems of the Belarusian State University, Minsk, Belarus and the CREATE Consortium, Naples, Italy, that have co-organized
the event, the University of Cassino and Southern Lazio, Cassino, Italy and the Belarusian State University, Minsk, Belarus that have supported it.

A special mention is to be given to the Organizing Committee members for their support, and to all the staff members and volunteers who put extraordinary efforts to make FANEM 2015 a memorable event.

We wish you a warm and pleasant stay in Mink.

Welcome, Сардэчна запрашаем, Benvenuti.

The FANEM 2015 co-directors:

Antonio Maffucci

Sergey Maksimenko
ORGANIZATION

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- C.R.E.A.T.E., Consortium, Naples, Italy
- Institute for Nuclear Problems, Belarusian State Univer., Minsk, Belarus

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NATO Advanced Research Workshop

Fundamental and Applied Electromagnetics

Workshop co-Chairs
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oral presentations

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2D crystals for nanoelectronics and beyond

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Keywords: 2D materials, biosensors, graphene, 2D heterostructures, transition metal dichalcogenides, tunnel-FET

Summary

The experimental demonstration of graphene in 2004, a truly one-atom thick layer of carbon atoms, has opened up a window to the two-dimensional (2D) world of materials. This has subsequently triggered a surge of research activities on various 2D crystals including single layers of hexagonal-boron nitride (h-BN), several dichalcogenides (such as MoS2 and WSe2), and complex oxides, which have been successively prepared using the micromechanical exfoliation technique employed for graphene. The ease of preparing these 2D crystals for demonstrating various prototype applications relies on the layered structures of their 3D bulk materials, where adjacent layers are held together by the relatively weak van der Waals bonds, while strong valence bonds firmly pack the in-plane atoms together. Two common features shared by all 2D crystals are the atomic scale thickness, which leads to novel physics and interesting applications, and the pristine interfaces that potentially promise stable chemical, electrical, and thermal characteristics. Atomic scale thicknesses (few Å/layer) of 2D semiconducting crystals and their controllable precise band gaps as a function of number of layers also enable the scaling of electronic devices without inducing performance variations. Moreover, seamless planar synthesis and stacking of various 2D crystals can be exploited to build novel lateral and vertical heterostructures, respectively. This talk
will highlight and discuss the prospects of such 2D crystals for designing low-power, low-loss and ultra energy-efficient active and passive devices targeted for designing next-generation green electronics [1-5]. It will also bring forward some applications uniquely enabled by 2D crystals, including sensors and high-frequency devices and circuits for improving quality of life, and discuss related challenges and opportunities.

**Acknowledgements.** This work was supported by the U.S. National Science Foundation (Grant CCF-1162633) and the Air Force Office of Scientific Research (Grant A9550-14-1-0268 (R18641)).

**References** (also see http://nrl.ece.ucsb.edu/publications)

An optical adventure in sexual deception

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Keywords: engineered biomimicry, bioreplication, conformal evaporated-film-by-rotation method, emerald ash borer, nano4bio method, polymeric visual decoy

Summary

Bioinspiration, biomimetics, and bioreplication constitute a progression of concepts and practices in the area of engineered biomimicry. The goal in bioinspiration is to reproduce a biological function but not necessarily the biological structure. Biomimetics is the replication of the functionality of a biological structure by approximately reproducing an essential feature of that structure. Bioreplication, the latest entry in the progression, is the direct replication of a structure found in natural organisms, and thereby aims at copying one or more functionalities. Bioreplication techniques currently include the sol-gel method, atomic layer deposition, imprinting techniques, and the conformal-evaporated-film-by-rotation (CEFR) method, as well as their combinations.

Bioreplication is now seeing success in the fabrication of polymeric visual decoys of the emerald ash borer (EAB), an invasive beetle species threatening North American ash trees species. Field observations showed that the location of a mate is dominated by a male EAB responding visually to the elytra of a female sitting in bright sunlight on an ash leaflet, suggesting that bioreplicated visual decoys could be efficacious in luring males. An industrially scalable
bioreplication process called the Nano4Bio was implemented. First, the CEFR method was modified to conformally deposit a ~500-nm-thick film of nickel on the upper surface of an euthanized female EAB. The nickel thin film was then strengthened by electroforming to yield the negative nickel die. Next, a positive epoxy die was made from the negative nickel die using several casting steps and one application of the CEFR method. A poly(ethylene terephthalate sheet (previously coated with a quarter-wave-stack Bragg reflector of green color on the upper side and a black absorber layer on the lower side) was hot stamped between the pair of matching dies.\(^2\) Comprehensive field experiments indicated that the decoys were more effective than pinned dead female EABs in attracting male EABs; furthermore, the replication of fine-scale features of the beetle elytra in the decoys was found to be responsible for success.\(^3\)

In a simpler bioreplication process,\(^4\) a multi-cavity negative die of nickel was made from an array of several euthanized EAB females. This die was used to fabricate multiple decoys simultaneously by casting and thermal curing of poly(dimethyl siloxane). Finally, the decoys were sprayed by first a black paint and then a metallic green paint. Visual deception for sex is expected to control other pest species too.

References

The use of color centers in diamond for the local nanoscale measurements and magnetic field imaging

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Keywords: diamond, nitrogen-vacancy color centers, quantum cryptography

Summary

Single nitrogen-vacancy (NV) color centers in diamond are, owing to the unique and advantageous combination of their optical, spin and material properties, one of the most promising candidates for implementation of emerging quantum technologies. Initially main efforts have been directed towards the quantum information applications of the NV centers and great progress has been achieved during last decade in development of quantum registers for quantum computers on coupled electron-nuclear NV-\textsuperscript{13}C spin systems and, as well, in single-photon source for quantum cryptographic systems (see. e.g. [1,2] for review). Later it was demonstrated that the NV centers offer also the unique possibilities to be employed as a nanoscale sensor for detection and imaging of weak magnetic fields with the potential to provide few $pT/\sqrt{Hz}$ sensing and nanoscale spatial resolution at ambient conditions [3] thus allowing to detect individual electron [4] and even nuclear [5] spins at distances in few nm. Moreover, nanosized diamonds hosting single NV center can be used to detect the fundamental electric charge at distance $\sim$25 nm [6] and, as well, to measure local temperature distribution within individual living cell [7]. Pressure can be measured by the same technique [1, (2014)]. These exciting perspectives have
triggered vivid experimental activities in the emerging field of ‘NV nanosensing/nanometrology’. Here we are presenting short review of a modern state in this field along with our most recent results [8-10] on imaging the two-dimensional profile of the magnetic field using the photoluminescence spin-readout return from NV centers, captured and delivered by the optical fiber.

References

Carbon, a unique model material for condensed matter physics and engineering science

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Keywords: carbon materials, nanomaterials, nanotexture, physical properties

Summary

Carbon is a unique element that allows preparing objects having extremely versatile and controllable properties. Carbonaceous materials can thus present chemical and thermal resistance, electrical conductivity, conductive or insulating thermal character, airtightness or permeability, porosity or not, surface areas sometimes exceptionally high, weightlessness, high mechanical resistance or ductility. This non-restrictive list of sometimes very antagonistic properties is the result of the outstanding variety of the textures that the carbon element may generate. To each particular texture, related to relative proportions of atom layers either parallel or corrugated, with possible sp2 or sp3 hybridising, corresponds one given functionality, and the modification of the texture induces that of the related properties [1]. For instance, the most suitable nanotexture for one given application can be achieved through the use of relevant precursors associated with convenient thermal history, as well as with appropriate post-treatments if required. Nanotexture has a direct impact on microporosity (pore size below 2 nm), whereas meso- (2 – 50 nm) and macroporosity (> 50 nm) can be controlled through the way the carbon precursors are processed. The process and the heat-treatment of well-chosen precursors therefore
allow controlling pore size distribution and total volume, connectivity and morphology. Besides, the surface of carbon can be functionalized, either for grafting various chemical species or for making it more or less acidic or basic, or more or less hydrophobic or hydrophilic. In addition to these key advantages that most other materials don’t have, carbon is far cheaper, especially if biosourced precursors are used.

Whereas a huge number of published works now deal with the most recent and “fashionable” carbon nanomaterials, such as nanotubes, graphene and their relatives, most people ignore that many other carbon forms are available and worthy of interest, such as glasslike carbon and the innumerable carbon forms presenting intermediate disorder between graphite and amorphous carbon. To cite P.L. Walker, one of the “giants” of carbon science, carbon is indeed “an old but new material” [2]. Fig. 1 thus presents a few examples recently obtained using natural polyphenols as carbon precursors [3]. This presentation will focus on the many carbon materials which can be prepared for plenty of engineering applications, or for condensed-matter physics studies.

![Figure 1: Examples of carbon materials derived from tannins. From left to right: cellular vitreous carbon foam; porous carbon microbeads; emulsion-templated carbon monolith; N-doped carbon microspheres; ordered mesoporous carbon.](image)

**References**

Graphene has been utilized in a numerous photonic and optoelectronic applications such as transparent electrodes, saturable absorbers, ultrafast transistors and optical modulators [1]. However, a metallic catalyst is needed for graphene synthesis, while incorporation graphene into photonic and optoelectronic devices requires deposition graphene directly on insulators and/or semiconductors on the prescribed location. Here we propose a technique for selective graphene growth directly on a pre-patterned dielectric substrate.

In the experiment, we formed grating structures with various periodicities (ranging from 200 nm to 4 µm) on a silica substrate by electron beam lithography. This pre-patterned substrate was covered by a 180 nm thick copper film and placed in the CVD chamber (see Ref. [2,3] for details). In the CVD process that was carried out at temperature of 950 °C, the Cu film will liquidize and form a pattern prescribed by the morphology of the substrate. A few layer graphene nanostructure, which was grown on the silica/copper interface, can be revealed by etching the copper remains (see Fig. 1).
Fig. 1. (a) After the CVD the intact copper layer receded forming copper ribbons aligned by the grating lines (grating line widths 600 nm – 1000 nm). (b) Removing the remaining copper reveals a few layered graphene (FLG) areas beneath copper.

In conclusion we demonstrate a transfer free technique in order to deposit graphene selectively without post patterning. This technique should prove to be useful when prepatterned structures, such as optical gratings or plane waveguides are needed to coat with graphene.

References

Dielectric properties of MWCNT/epoxy composites with oriented distribution of the filler

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Keywords: permittivity, shielding efficiency, absorption of multi-walled carbon nanotubes, (MWCNTs)/epoxy composite.

Summary

The work presents the results of investigation of the electrical properties such as conductivity, permittivity, shielding efficiency, absorption of multi-walled carbon nanotubes(MWCNTs)/epoxy composites (CMs) with oriented distribution of the filler in a frequency range 26-55.5 GHz.

In order to obtain the composite with oriented distribution of Chemical vapor deposition MWCNTs in the epoxy resin matrix AC electric field of 125 kV/m with frequency at 15 kHz was applied to well dispersed pristine MWCNTs/epoxy mixture. Content of nanocarbon filler in CMs was varied from 0.05 to 1 wt%.

The formation of ranks of nanotubes under AC electric field action have been established by the methods of optical spectroscopy.

As a result of MWCNTs alignment, the composites showed significant anisotropic properties for permittivity, shielding efficiency, absorption and electrical conductivity. It was found that the resistivity of aligned MWCNTs/epoxy composites in the direction parallel to the MWCNTs alignment is about three orders of magnitude lower than that of without electric field treatment and is about 20 times lower than that in the perpendicular direction.
The influence of MWCNT orientation in MWCNTs/epoxy composites with different MWCNT concentrations on dielectric permittivity have been investigated. As expected, the permittivity increases with the increase of the MWCNT concentrations. It is also have been revealed that the anisotropy of permittivity in the direction parallel to MWCNT axis the permittivity is higher than in perpendicular. In the frame of modified Maxwell-Garnett model [1,2] which take into account the character of distribution of MWCNT in polymer matrix the behavior of dielectric permittivity of composites have been analyzed. It was found that anisotropy factor for developed composite is 2 which indicate rather high degree of MWCNT aligned by AC electric field under polymerization.

The ordering of MWCNT in polymer matrix allow to essential increase the absorbing peak value and bandwidth. For example, the absorbing peak value increase from -13,8 dB to 23,79 dB (d=3,4mm) and from -10,3dB to 31,37 dB (d=2,6mm) for composites with 1wt.% MWCNT for random distribution of CNT and E II CNT axis, respectively. And the strong absorption ranges (>10 dB, e.g., ) reach 5.15, 6.35 GHz for d=3,4mm and 2,6mm, respectively, that is in~1,4 and 4 times larger the strong absorption ranges for composites with random distribution of MWCNT in poilymer matrix. It was shown that the results of simulations in frame transmission line theory [3] of the reflection loss of the MWCNT-epoxy composite for different concentration of filler in composites using experimental dates for $\varepsilon''$ agree reasonably well with the experimental results.

**Acknowledgements.** This work was supported by NATO project NUKR.SFPP 984243

**References**

Electrical conductivity of graphene: a time-dependent density functional theory study

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Keywords: graphene, DFT method, conductivity

Summary

Among their remarkable properties, graphene and graphene-related materials constitute an effective vehicle for the realization of new devices operating at terahertz (THz) frequencies [1]. At present, the role of THz plasmons in the conductivity of graphene is studied by means of tight-binding (TB) calculation schemes [3], where the only relevant contribution is brought by the conical energy band dispersions of $\pi$ and $\pi^*$ electrons close to the Fermi energy. We present, in this work, a full quantum characterization of the plasmon-induced conductivity in free-standing graphene, both in the frequency and time domains, using time dependent (TD) DFT at the level of linear response (LR) theory, and under the random phase approximation [5]. At the same time, compare of our ab initio tools with a more common semi-phenomenological approach leading to the Kubo-Drude (KD) conductivity [5], and discuss its limits. For example, in Fig. 1 we show the frequency dependent EM response of an ideal graphene sheet, together with the time dependent conductivity. To mimic the effect of positive doping, we have shifted the Fermi level of pristine graphene of an amount $\delta\mu\leq0.1$ eV, above the Dirac cone. We see that the agreement between the KD and TDDFT approaches is quite good at frequencies below ~40 THz (or at times larger than 0.5 ps). On the other hand, significant deviations appear at higher frequencies (above ~50 Thz) and short times (below ~0.2 ps).
Such a disagreement becomes more and more explicit if we consider realistic situations involving graphene flakes, disks, ribbons, and other low-dimensional arrangements of carbon atoms, with one or more spatial dimensions being just one atom thick.

![Fig. 1.](image)

Frequency dependent conductivity (left), resistivity (middle), and time-dependent conductivity of doped graphene as calculated from the KD and TDDFT approaches.

In conclusion, we propose an accurate and reliable procedure to explore plasmon propagation in systems where the conical dispersion of $\pi$-band electrons at the Fermi level, is possibly distorted either by the geometry of carbon atoms or by presence of metal contacts and supporting substrates [6].

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Electrodynamics of graphene/polymer multilayers in the GHz frequency domain

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Keywords: graphene, metamaterials, RF shielding, simulation

Summary

The electromagnetic properties of a solid materials can be formulated in terms of their surface admittance and impedance. It will be shown that the surface impedance and admittance of a plane-stratified medium, where the dielectric permittivity varies only with the coordinate normal to the surface, are governed by a first-order Riccati differential equation. That equation can be solved in the form of a continued fraction when the permittivity is an arbitrary piece-wise constant function, as in ideal multilayers. From there, the reflectivity, transmittance and absorbance of any multilayered material can be obtained. As an illustration, this formalism will be applied to graphene/PMMA heterostructures. An optimum number $N$ of layers exists for which the absorption of GHz radiations by the graphene planes is maximum [1].

When the material properties are not uniform in the directions parallel to the surface, another approach must be used. In real samples, the graphene layers may be not homogeneous: grain boundaries, microscopic holes and microscopic dots (embryos of a second layer) are often present. Numerical calculations using the rigorous coupled wave analysis (RCWA) method demonstrate that the absorption of GHz radiations by the optimum graphene/PMMA sandwich is robust in the sense that it does not depend on these defects to first order in
concentration [2]. This property is not true when the number of layers deviates from the optimum value $N$.

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**References**

Coherent anti-stokes Raman scattering (CARS) spectroscopy and imaging of biological molecules on graphene layers: advantages and disadvantages

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Keywords: graphene, Raman spectroscopy, biological molecules

Summary

Modern CARS and Raman spectroscopy is used as analytical tool in modern biochemistry. CARS is known as attractive methods for imaging of biological molecules, and Raman spectroscopy is used more for analytical tasks. Application of CARS spectroscopy is limited by great complexity of CARS spectra. However, in contrast to crystals, CARS spectra of biological molecules are similar to those in Raman spectra. Difference between CARS and Raman spectra of biological molecules are negligible shift of some bands and shape band changes. This report is devoted to CARS and Raman spectra of thymine, adenine, DNA on graphene layers as well graphene-based materials peculiarities of these spectra. Enhancement of Raman spectra of biological molecules on graphene films up to 10³ and in CARS up to 10⁷ is analyzed and possible mechanisms are discussed.

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Graphene-enhanced metamaterials in THz applications

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Keywords: graphene, metamaterial, THz waves, multilayers.

Summary

Terahertz (THz) radiation is widely employed in a broad range of fields in biology, medicine, communication, security, chemistry, and spectroscopy. To expand the application of terahertz radiation new device designs and fabrication methods are needed. The ability of metamaterials to manipulate electromagnetic waves makes them natural candidates for THz optical components [1]. However, ranges of light manipulation can be strongly expanded by involving graphene as a structural component of metamaterials. The interplay between interband and intraband transitions in graphene allows converting a multilayer graphene/dielectric structure into a transparent and/or electromagnetically dense artificial medium in a narrow THz or infrared frequency range. The gate voltage can be used to electrically control the concentration of carriers in the graphene sheets and, thus, efficiently change the dispersion of the whole structure.

Placed inside a hollow waveguide, a multilayer graphene/dielectric metamaterial provides high-speed modulation of radiation and offers novel concepts for terahertz modulators and tunable bandpass filters. We exemplify it showing performance of waveguide-based terahertz modulators with high ON-state transmission and competitive energetic
efficiency: with a 50 meV shift of graphene’s Fermi energy, it is possible to switch between transmission and attenuation regimes [2]. Structured graphene layers embedded into dielectric (graphene wire medium) can be used to create a hyperlens. We propose a realistic geometrical design for the hyperlens for the THz radiation and proved that it can resolve two line sources separated by distance $\lambda_0/5$. Simulations were done with two approaches: heavy full-3D simulations and quick 2D hyperlens modeling via homogenization in one dimension [3]. Both approaches exhibit close correspondence in results.

Furthermore, we analyze the origin of the hyperbolic dispersion behavior in graphene-dielectric metamaterials. It appears that TM-polarized plasmon-polaritons in individual graphene sheets hybridize to form volume plasmon-polaritons with hyperbolic metamaterial-like properties in the frequency range, where the imaginary part of the graphene conductivity significantly exceeds its real part. On the other hand, TE-polarized graphene plasmons-polaritons behave like long-ranged surface plasmon-polaritons in metal-dielectric multilayers, without any hints on hyperbolic-like dispersion [4]. We believe that graphene-enhanced metamaterials constitute a useful functional element for the THz-infrared integrated optics devices.

Acknowledgements. This work received partial financial support from the People Programme (Marie Curie Actions) of the European Union’s 7th Framework Programme FP7-PEOPLE-2011-IIF under REA grant agreement No. 302009 (Project HyPHONE).

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THz polarization control with chiral metamaterials

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Keywords: metamaterials, chirality, bianisotropy

Summary

In this talk we discuss our recent studies [1-3] on THz chiral metamaterials and the potential that they show for active and passive THz polarization control. Different metamaterial designs are discussed, showing giant optical activity, large circular dichroism and negative refractive index for circularly polarized waves. Incorporating properly photoconducting silicon in the metamaterial structures, optically tunable and switchable chiral response is achieved and demonstrated, allowing the metamaterials to be employed for active polarization control.

Finally we show that employing anisotropic “chiral” structures one can achieve additional polarization control properties and capabilities. Such a capability that we demonstrate in a three-dimensional anisotropic structure is asymmetric transmission for linearly polarized waves.

Acknowledgements. This work was supported by Greek-GSRT project ERC02: EXEL

References

Terahertz-range applications of nanocarbon-based materials

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Keywords: nanocarbon, terahertz range, nanocomposites, carbon nanotube, graphene

Summary

Optical properties of CNT films can give us information about electronic transport in nanotube at high frequencies. Especially it is important in terahertz range where the response from individual tube is very small and cannot be detected. Far infrared and terahertz conductivity of SWCNT film demonstrate non-Drude behavior, which can be described by imposing some resonant term over the Drude conductivity law. We demonstrate theoretically the dominant role of finite size effect in the non-Drude conductivity of CNT films due to the strong slowing down of surface polariton in CNT \cite{1,2}. Significant screening effect is demonstrated to be inherent to electromagnetic response of MWCNTs films at gigahertz frequencies while it practically disappears in the THz range. The main features of the gigahertz and terahertz spectra of effective permittivity and electromagnetic interference shielding efficiencies of a MWCNT-based composite observed previously in experiments are discussed. The experimental evidence of the CNT length-dependence of the THz spectra of SWCNT films \cite{3} is reported. The experiments have been carried out with films comprising calibrated in length CNTs \cite{4}. We show blue shift of the THz peak in conductivity spectra of SWCNT thin film with decreasing SWCNT length. Thus, experimental results demonstrate the phenomena of localized plasmon resonance in
SWCNTs and prove theoretically predicted antenna effect in SWCNTs in terahertz and far-infrared ranges. The concept of CNT as a THz range traveling wave tube [5] is also presented.

We report experiment and theoretical results [6] on terahertz wave transmission through sandwich structure which consists of graphene mono-layers interlaced by submicron layers of polymethyl methacrylate (PMMA). Measurements of THz transmission for free standing graphene/PMMA sandwiches (one and three graphene layers, not supported by quartz substrate) were performed in the frequency range from 100 GHz to 3 THz, by time domain terahertz spectrometer (EKSPLA, Vilnius Lithuania) based on femtosecond laser and GaBiAs photoconductive switch as THz emitter and detector. Measurements demonstrated the remarkably high absorption of terahertz waves by graphene sheets.

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Full-wave techniques for the multi-physics modeling and design of nano-structured devices

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Keywords: Graphene, plasmons, field-effect transistor, quantum transport equations, graphene, multi-physics modeling.

Summary

Full-wave multiphysics techniques aimed at the investigation of the combined electromagnetic-coherent transport phenomena in carbon-based nano-structures/devices are presented. Advanced numerical tools, in the frequency (energy)-domain and time-domain and in multi-scale environment are derived. The quantum transport is modeled by i) discrete Hamiltonians at atomistic scale, ii) Schrödinger equation, and/or Dirac/Dirac-like eqs. at continuous level. In the frequency-domain, a rigorous Poisson-coherent transport equation system is provided.

In the time-domain, we avail a novel Schrödinger/Dirac-based transmission line matrix (TLM) solver for the self-consistent analysis of the electromagnetic-coherent transport dynamics in realistic environments. It is highlighted that the self-generated electromagnetic field may affect the dynamics (group velocity, kinetic energy etc.) of the quantum transport.

Multiphysics models provide simulation tools for applications ranging from microwave up to Terahertz. The computational framework deals with the multi-scale nature of the coupled domains, from atomistic- through the nano-, up to the meso-scale. In some cases, in particular in the non-ballistic regime, analytical expressions for the
electromagnetic response of nanostructured material can also be derived in a macroscopic framework.

On the basis of the aforementioned theoretical models, and by using advanced space-time discretization techniques, we have developed dedicated numerical tools. We are now working along on the following problems, spanning from the nano-scale to the mm/em-scale: i) basic research on the analysis of time transients in the describing the behavior of high energy carrier bands, with the onset of non-linear phenomena due to impinging external electromagnetic fields and to thermal effects in graphene/CNT, as deriving from ballistic path reduction due to phonon scattering; ii) optimization of the self-consistent model of carbon nano-transistors and related devices, which include several applications SW/MW-CNT-FET, GNR- FET, p-n junction and CNT photodiode, many-terminal GNR circuits, Y- and T- GNR junctions, rectifiers and demodulators; the graphene/CNT-metal transition is a key point in this research line; iii) use of Dirac-like equations of graphene to describe valleytronic and spintronic devices, that exploite the ballisticity and coherence of charge carriers over long distances; iv) analysis of microwave and terahertz devices, exploiting approximate non-ballistic models of graphene and CNT, such as the simple Drude approximation, transmission line (lumped circuit) models. The applications considered in the last point include graphene-patch antennas, CNT-wire antennas, microwave absorbers, Faraday rotators, interconnects, slow-wave transmission lines, and plasmonic devices.
Circuital Modeling of Carbon Interconnects in the THz range

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Keywords: Carbon nanotubes; Graphene Nanoribbons, Terahertz interconnects, Tunneling effect.

Summary

The Terahertz range (0.1 – 10 THz) is one of the last unexplored frontiers in electronics, which has gained more and more interest in the recent literature [1]. Accessing this “boundary” region between electronics and photonics has been a challenge for decades. Nowadays, the rapid progress in nanoscience and nanotechnology is giving an unprecedented push to the THz applications: a promising technological solution is the use of carbon nanomaterials like \textit{carbon nanotubes} (CNTs) or \textit{graphene nanoribbons} (GNRs) [2]-[3]. A bottle-neck for the THz technology has been the lack of low-loss interconnects, even for chip to chip links. This limit imposes that the circuit elements like sources, detectors or antennas, must be either placed in direct proximity to one another or coupled by free space optical links. The packaging solutions realized with conventional materials, although the losses can be lowered to reasonable values, exhibit sizes too big to be suitable for compact low-cost THz systems. Recently, the carbon interconnects have been proposed for the THz packaging [4]. In view of such applications,
there is the need to reconsider the equivalent circuit models for carbon
nano-interconnects widely adopted in the microwave range [4]-[6].

In this paper we introduce a correction in the above circuit models
that accounts for tunneling effect between adjacent CNT shells or GNR
layers, usually negligible for frequencies up to hundreds of GHZ. In the
THz range, isolated CNTs exhibit resonances due to slow propagation
velocity: this is a well-known result at the basis of the possibility of
using such structures as nano-antennas [7]. Therefore, the CNTs, as well
as the GNRs, can be used as THz interconnects only for electrically
short lengths. However, the THz analysis performed by including the
tunneling effect highlights a dispersive behavior and new resonances,
also for electrically short lines. Thus, the tunneling reduces the
frequency range of utilization of carbon interconnects (for a fixed
length), or equivalently reduces their lengths (for fixed operating
frequencies).

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Electromagnetic and quantum interference on nanoscale: new concept of electromagnetic compatibility in nanoelectronics

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Keywords: electromagnetic compatibility, spurious couplings, quantum effects, ballistic effects, nanoelectromagnetics

Summary

The present-day stage of the development of electronics is characterized by intensive penetration of nanotechnologies into the production processes. As a result, new frequency ranges, from terahertz to optical, are actively explored for the information transmission and processing. The process is accompanied by the growth of the level of integration and the decrease of the operation power. It means that the electromagnetic compatibility (EMC) on the nanoscale is expected to become a complicated and acute problem in the nearest future.

It is no longer possible to use the classical electrodynamics approach on the nanoscale, because quantum phenomena have to be taken into account. For instance, the capacitances and inductances of nanocircuits contain additional components of the quantum nature, which do not explicitly depend on the geometrical parameters.
On the nano-level, the size of nanostructures in one or more dimensions is comparable to the electron de Broglie wavelength at room temperature. Consequently, a number of quantum effects (electronic band structure, energy spectrum discretization, phonon spectra, ballistic charge propagation, few-body correlation effects, tunneling, resonant scattering, stress/strain, interface effects, etc.) have to be taken into account.

A new concept [1] of nano-EMC for nanoelectronics, based on the synthesis of the classical electrodynamics and quantum transport theory in nanostructures, is presented. The classical EMC concepts such as coupling, shielding, and impedance matching, should be reconsidered taking into account quantum correlations and tunneling, as well as spin-spin and dipole-dipole interactions. As a result equivalent circuits will contain additional elements of quantum nature, which significantly influence the EMC, and a range of effects that are important for nanoEMC can be identified, like the quantum nonreciprocity [2] which does not have any classical analogs.

The main concept is illustrated by the example of carbon nanotube based interconnects.

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Design and applications of UWB nano-antenna arrays

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**Keywords:** nano-antennas, arrays, wideband, infra-red, optical, impedance

**Summary**

Dual-Vivaldi nano-antenna arrays were designed, fabricated, and optically characterized in the infrared (IR) and visible regimes [1]. The antenna arrays were characterized by measuring the scattered light at IR and visible spectral ranges [2]. A novel technique for antenna and load impedance measurements using scattering data has been developed. The radiation efficiency and the spectral response of the antennas were found to be in good agreement with numerical simulations. The results presented here demonstrate the extremely wideband nature of the Dual-Vivaldi nano-antennas and the strong impact of load at the antenna terminals on its scattering response [3]. These properties, as well as their many degrees of freedom for design, render the Dual-Vivaldi nano-antennas excellent candidates for optical sensing applications and energy harvesting. Various applications of nano-antennas will be discussed.

**References**

Strong-electric-field effects and antenna resonances in single-wall carbon nanotube films

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Keywords: terahertz, carbon nanotube, strong electric field, resonance

Summary

Single-wall carbon nanotubes (SWCNT), because of their unique features, are assumed to be one of key-materials in the family of nanostructures since they can serve as an important constituent in many nanodevices. SWCNT aggregates (films, networks, mats) consisting of a large number of SWCNT exhibit uniform physical and electronic properties what is suitable for practical applications such as thin CNT film field effect transistors [1], conductive and optically transparent layers for optoelectronic devices [2], interconnects for large scale integrated circuits [3].

In particular, SWCNT layers are important for detection of electromagnetic radiation in far-infrared range where compact broadband and sensitive detectors still remain an issue. In this work, SWCNT structures are prepared as coating layers on optical silica fibers. It is demonstrated that SiO₂-CNT structures can detect electromagnetic waves within 0.5– 7.3 THz range at temperatures 4.2–70 K. The photoconductive photoresponse is related to the THz-induced hopping via intratube defects and intertube contacts. At certain THz
frequencies the photosignal exhibits resonant behavior which is related with antenna effects of metallic SWCNT of finite length. Calculations made using Waterman–Truell formalism support the experimental data. Furthermore, to improve understanding of electrical transport mechanism in SWCNT films DC conductivity experiments have been carried out in wide ranges of temperatures and DC electric field strength. Special attention has been paid to strong electric fields (up to $10^5$ V/cm) when applying electrical pulses of nanosecond duration to make Joule heating insignificant. It was found that localization of carriers as well as tunneling through the insulating barriers between conducting regions takes place in SWCNT films. The crossover from semiconductor behavior to metallic behavior in strong electric field is described using modified fluctuation induced tunneling model. These findings are relevant in modern electronic devices which are continuously being scaled down to nanometer dimensions what leads to high electric field effects induced by a moderate bias voltages.

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**References**

Collective spontaneous emission and quantum - optical nanoantennas

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Keywords: collective spontaneous emission, d-d interactions, timed Dicke states, phased-array nanoantennas

Summary

The collective spontaneous emission of ensembles of interacting oscillators is a matter of fundamental interest in quantum optics. Indeed, many different physical effects can be modeled by a system of quantum oscillators using the appropriate physical mechanism for the interaction. Atoms, molecules, ultracold trapped atoms in optical lattices, ions in Paul traps, Josephson qubits, semiconductor quantum dots (QDs), can be considered as a single oscillators, described in the simplest case by a two-level model. The dipole-dipole (d-d) interaction, tunneling, Förster nonradiative coupling, long-range radiative coupling, spin-spin exchange interactions are examples of the different interaction origin. In a realistic situation, one of the interaction mechanisms is usually dominative.

In this talk we study the collective spontaneous emission of timed Dicke states in a periodic 2D-array of quantum dots (QDs) coupled via d-d interactions. The analysis is based on the master equation technique.
We obtained the simple analytical relations for the spontaneous decay rate, collective Lamb shift and radiative pattern. The collective spontaneous emission in QD-array manifests itself in the strong directivity, whereby the radiative pattern consists of a set of narrow radiative lobes. The direction of the main lobe is dictated by the pumping direction, while the other lobes correspond to diffractive rays due to the periodicity. The influence of d-d interactions on the radiation decay of timed Dicke states in QD arrays is similar to Parcell effect for the single-particle excited states, in spite of another physical origin. We introduce the concept of “equivalent” structured photonic reservoir, which allows using the notion of photonic density of states, as well as a methods of its calculation for different types of arrays. We show that the “equivalent” structured photonic reservoir for rectangular 2D-array has a form of a rectangular perfectly conductive waveguide. For lattice periods comparable to the radiation wavelength the decay rate shows a set of sharp peaks due to Van-Hove singularities similar to the Purcell-effect in photonic crystals.

The direction of the diffractive rays is dictated by timing. Therefore, digital directional tuning of the radiation pattern becomes accessible via optical means (by variation of the pump wave direction). We discuss an important problems appearing in the implementation of QD-arrays to supply of the coherent behavior of the single emitters for a rather long value of time. We demonstrate some experiments which show that rather large QD-arrays enable to exhibit the coherent behavior for rather high and even room temperatures [1]. The collective spontaneous emission in arrays looks promising for fabrication of optically tuned phased-array nanoantennas intended for the directive transmission of digital optical signals in quantum informatics.

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References
Phonon-assisted radiofrequency absorption by gold nanoparticles resulting in hyperthermia

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Keywords: biological tissue heating, phonons, confinement, longitudinal acoustic vibrational mode

Summary

Among methods allowing for hyperthermia in biological tissues, the one based on the radiofrequency (RF) absorption by gold nanoparticles (GNPs) received in the last years much attention [1,2], due to its important advantage - a deep penetration of the RF radiation into biological tissue (~30 cm at frequencies ~ 10 MHz). Experiments carried out at 13.56 MHz revealed that the heating rate (HR) depends on the particle size, namely that smaller particles are heated faster, presumably because of their higher resistivity. However, the exact physical basis of heat generation by nanoparticles remained so far unclarified. This is a serious obstacle for grasping the HR / particle size relation and hence for making "intelligent choice" of the GNP size, tailored to the particular use. For example, one may wish to assure an enhanced specific absorption rate to heat the GNP to necessary temperatures at minimum released power, avoiding at the same time an unnecessary heating of normal tissues during hyperthermia.

The experiments imply that the smaller the size of GNPs, the higher their HR; this was so far confirmed throughout the range of sizes from ~250 nm down to ~5 nm diameter. In our opinion, the observed size dependence of the HR in GNPs manifests an involvement of phonons, specifically of longi-tudinal acoustic vibrational modes (LAVMs), in the absorption of RF photons by the Fermi electrons.
We suggest a physical model of the size effect in heat generation in GNPs, which also accounts for a reduction of heat generation as the GNPs get aggregated. In this model, the LAVMs (dominating in the distribution of vibrational density of states) play an important role - an apparently novel element in the related theory framework. We stay within the one-electron approximation and account for the discreteness in energy and momenta of both electrons and LAVMs. According to our model, the heating of GNPs is thought to consist of two consecutive processes: first, a Fermi electron absorbs simultaneously a RF photon and the energy from a LAVM available in the GNP; hereafter the excited electron is scattered on the GNP's boundary, emitting a LAVM with the energy higher than that of the previously absorbed LAVM. The model predicts that the GNPs, in order to be effectively heated, should possess diameters of ~6.65 nm, i.e., very close to the experimentally inspected ~5 nm. The matching conditions are satisfied for the momenta of a Fermi electron and of the LAVM being coplanar. The absorption band is expected to be very wide (~10 MHz-3 GHz). This allows the use of frequencies typical for the conventional RF hyperthermia (without conducting nanoparticles). The energy release in the GNPs can be optimized by tuning the RF frequency, searching a compromise between the HR energy transfer efficiency and a penetration depth of the RF radiation into the biological tissue. As a possible extension of our study, GNPs containing Ta or Fe are expected to be more effective heaters compared to nanoparticles of pure gold, due to enhanced electron DOS at the Fermi level. Gold nanoparticles with rare-earth impurities are also brought into consideration as promising for the RF hyperthermia with conducting nanoparticles.

The importance of the present work follows from the fact that the cancer specialists seeking approval for human clinical trials on the basis of their experimental results remain thus far in the dark in what regards the physical mechanism behind the observed trends.

References

**Injection and control of photocurrents in nanocarbon materials**

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**Keywords:** graphene, photon drag, THz emission

**Summary**

Strong and broadband light absorption in graphene and other nanocarbon materials with sp2 hybridization of electron orbitals allows one to achieve high carrier densities essential for observation of nonlinear optical phenomena. This makes graphene a unique playground for studying many-body effects. Being of strong fundamental importance, these effects also open a wide range of opportunities in photonics and optoelectronics. Here, we make use of strong photon-drag effect to inject and optically manipulate ultrafast photocurrents in graphene at room temperature. Direction and amplitude of the drag-current induced in graphene and nanographite are determined by polarization, incidence angle and intensity of the obliquely incident laser beam [1]. We also demonstrate that the irradiation of graphene with two laser beams of the same wavelength offers an opportunity to manipulate the photocurrents in time domain [2]. In the experiments, we used CVD graphene transferred to dielectric substrates and containing from 1 to 40 atomic layers. Samples area was about 1 cm². To induce photocurrents we employed a 1 kHz Ti:Sapphire femtosecond oscillator/amplifier (pulse width 120 fs, central wavelength of 790 nm) and optical parametric oscillator (pulse width 10 ns, a central wavelength tunable in the range from 1150 nm to 4000 nm). The light-induced current strongly depends on the polarization azimuth and vanishes at normal incidence.
At a finite incidence angle, the photocurrent magnitude shows $\sin^2\varphi$- and $\cos^2\varphi$-like behavior. At the femtosecond excitation [3], the ultrafast currents results in the THz emission. Our analysis shows that the THz emission originates from the photon drag effect, i.e. from the, transfer of the photon momentum to free carriers.

All-optical control of photocurrent was demonstrated in the two-beam experiment when sample was irradiated with two mirror-reflected beams (see Fig.1b). At a zero time delay between the excitation pulses of the same intensity, the photocurrents completely compensate each other resulting in a zero net current. Since the drag current strongly depends on the polarization of the excitation beam, the net current was tuned by rotating the polarization plane azimuth of the first beam. The net current signal waveforms as a function of the first beam polarization azimuth obtained at nanosecond excitation is presented in contour plot on Fig.1c. The temporal profile of the net current can be controlled by varying time delay between excitation pulses (see Fig. 1d).

References

The first carbon periodic cellular architectures [1], in the form of new tetrakaidecahedra 3D meshes, are reported and investigated in this communication. They were prepared in hydrothermal conditions by a template method based on polymer periodic structures of the same geometry, and fabricated by a 3D printer using photocurable resin. Several formulations based on resorcinol-formaldehyde were tested, and the best ones were those using low concentrations of resorcinol at 150°C in a pressurised solution of nickel nitrate. After pyrolysis at 1000°C, catalytic graphitisation was demonstrated by TEM, XRD and Raman studies. The higher was the amount of nickel, the higher was the resultant graphitisation level.

The electromagnetic (EM) properties of carbon periodic cellular architectures were investigated in the 26-37 GHz (Kα-band) and 20 Hz – 35 GHz, frequency ranges, respectively. Significant EM interference shielding efficiency (EMI SE) was found at microwave frequencies for
all materials. 2 mm of material is almost not transparent to microwave radiation and, depending on bulk density and primary cell size, the EM response can be mainly accounted for by either reflection (up to 80% for the densest foams) or absorption. For thicker samples, being 4 mm, EMI SE reached 40 dB.

The microwave performances of carbon foams reported here open new routes for producing effective EMI shields and filters. Electromagnetic probing also proves that carbon periodic cellular architectures due to their periodic structure could behave as photonic crystal in the microwave – terahertz range.

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**References**

Synthesis and optical properties of semiconductor colloidal quantum nanoplatelets

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Keywords: semiconductor nanoplatelets, preparation, structure, absorption, photoluminescence

Summary

Thin, atomically flat semiconductor nanocrystals (nanoplatelets) prepared by colloidal chemistry routes represent the new class of quantum-sized objects with strong quantum confinement transversely to their surface planes. CdSe nanoplatelets are good model objects to study basic optical properties of 2D semiconductor nanocrystals depending on their lateral size and thickness. The thickness of CdSe nanoplatelets can be precisely varied from 2 to 6 Cd-Se monolayers which results in spectrally narrow excitonic optical transitions both in absorption and photoluminescence [1]. Here, we demonstrate that sharp excitonic absorption bands of CdSe nanoplatelets of different thickness allow for the observation of large electro-optical Quantum Confined Stark effect, much stronger than in the corresponding 1D (nanorods) or 0D (quantum dots) CdSe nanoparticles [2].

We demonstrate also, that not only core CdSe, but more complex CdSe/CdS and CdSe/ZnS core-shell nanoplatelets with stable and bright photoluminescence can be synthesized which opens the way for practical applications of nanoplatelets as efficient light convertors and fluorescent markers. The two-photon absorption and photoluminescence parameters are also discussed in this case. Changing the conditions for epitaxial overgrowth of CdSe core nanoplatelets from 2D to 1D we obtained unique core-wings CdSe-CdS, CdSe-CdTe and CdTe-CdSe heteronanoplatelets [3,4]. CdSe-CdS heteronanoplatelets possess type I
optical transitions and show a photon antenna effect when the excitons, photogenerated in wide gap CdS wings migrate to the narrow gap CdSe core and recombine radiatively resulting in enhanced photoluminescence signal. CdSe-CdTe and inverted CdTe-CdSe epitaxial core-wings heteronanoplatelets possess type II optical transitions due to band offsets which results in the efficient electron and hole separation between the core and the wings. The spatial charge separation results in the indirect radiative exciton recombination with surprisingly high (50%) photoluminescence quantum yield and large Stokes shift. The intrinsic and efficient charge separation in type II core-wings nanoplatelets can be important for practical applications as efficient photovoltaic devices.

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References

Non-classical light emission from GaN nano structures

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Keywords: non-classical light, quantum dot, quantum wire

Summary

Studying quantum effects in nitride-based nanowires and quantum dots with diameters scaling down to a few nanometers is hindered by their still mostly bulk-like properties. A drastic diameter reduction towards the domain of the so-called quantum wires (QWRs) and dots (QDs) facilitates true one dimensionality of the structures exhibiting confinement in two directions, while the third direction can straightforwardly be tailored. If the QWR and QDs length is now sufficiently reduced one can approach the transitional regime between one- and zero-dimensional structures with drastic effects on the observed emission line characteristics and photon statistics.

First, GaN QWRs are segregated by plasma-assisted molecular beam epitaxy (PAMBE) on an AlN/GaN nanowire template. The around 1.5 - 4 nm wide QWRs were deposited on the a-plane facets formed at the six intersections of the m-plane sidewalls exposed by individual AlN/GaN nanowires. By tuning the QWR length from 500 nm to below 50 nm we can approach the regime of QD-like emission characteristics as demonstrated by the comparably narrow (1 – 10 meV) emission lines observed in µPhotoluminescence spectra. Interestingly, some of the emission lines exhibit a linear scaling behavior with excitation power pointing towards their excitonic character, while other emission line intensities rise in a quadratic manner. This scaling behavior for the two emission lines is typical for excitonic (X) and biexcitonic (XX) emission arising from a single GaN QWR. Most of such individual emission lines
even show characteristic traces of single-photon emitters like GaN/AlN quantum dots if their g2-correlation functions are considered. Temperature dependent series of g2-correlation functions for the exciton that is dominated by a bunching effect overlaid by a temporally narrow antibunching as a trace of the onset of single photon emission common for zero-dimensional structures. With the raise of temperature both phenomena rapidly fasten and approach the time resolution of the applied, UV-enhanced Hanbury-Brown and Twiss setup, leaving behind only a weak bunching trace in the g2-correlation function at a temperature of 30 K. However, by tuning the QWR length we gain access towards a tuning of such photon statistics, striding the borderline between one- and zero-dimensional structures.

Second, two-photon emission from the biexciton cascade of a single quantum dot, as representative of a four-level system, can exhibit a super-Poissonian photon distribution in contrast to the sub-Poissonian statistics of, e.g., polarization-entangled photon pairs. In particular, we demonstrated experimentally and theoretically how bunched two-photon emission from a single quantum dot can be tuned by means of the biexciton binding energy, pump power, and temperature up to 50 K. Variation of these parameters enables control over the emission from sub-Poissonian one- to super-Poissonian two-photon processes, as explicitly expressed by the reported bunching phenomenon. Alternative common interpretations for a bunching signature in the g(2) -correlation function based on purely biexcitonic single-photon emission or spectral diffusion have been ruled out demonstrating the importance of two-photon processes in the biexciton cascade. Moreover, we outlined that the antibunching in the g(2) -correlation function of a “single” photon emitter can be overlaid by the reported bunched two photon process as long as the biexciton state is still populated. Our results prove that the full nature of the four-level system must not be neglected as in two-level based approaches, which evidently only consider one-photon processes.
Current approaches of spin torque transfer magnetic random access memory devices

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Keywords: spin-transfer torque MRAM, P-MTJ, synthetic antiferromagnetic layer

Summary

Current DRAM technologies have been intensively developed for information recording/storage fields. However, as the design rule has been scaled-down to sub-20 nm, it has been predicted that a capacitor used for the DRAM will meet the physical/technological limit [1]. Therefore, various next-generation memories such as ReRAM, MRAM, and PCRAM, etc. has been widely investigated to overcome this limitation. Among the recently considered next-generation non-volatile universal memories, magnetic random access memory using spin-transfer torque mechanism (STT-MRAM) is one of the most potential candidates for use in practical devices beyond the design rule of 20 nm due to its fast operation speed and low power consumption. Especially, STT-MRAMs using perpendicularly magnetized ferromagnetic layers is a key approach to ensure the low critical current density ($J_c \leq 4.7 \text{ MA/cm}^2$) and high thermal stability of $\Delta=74$, compared to in-plane STT-MRAMs [2]. To fulfill these requirements, the multilayer (ML) structures such as Co/Pt, Co/Pd, and Co/Ni have been studied [3], but these MLs possesses quite high damping constant $\alpha$, which results in high $J_c$ value. Recently, Ikeda et al. has reported the PMA properties of CoFeB thin film, which has reasonably high spin polarization value and low $\alpha$ value. Nowadays, magnetic tunnel junctions (MTJs) using the synthetic antiferromagnetic layer (SyAF) composed of Co/Pt or Co/Pd
MLs attached to CoFeB/MgO/CoFeB core junction has become the standard stack for realization of the $p$-STT MRAMs. Industrial applications of STT-MRAMs basically requires CoFeB/MgO/CoFeB core junction and synthetic antiferromagnetic layer (SyAF) that consists of Co-based multilayers with high perpendicular magnetic anisotropic energy under annealing. Here, four critical challenging issues including TMR ratio, critical current, thermal stability and tunneling barriers will be discussed, along with possible origins for enhanced PMA characteristics.

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**References**


Models of all-optical switching in nanogranular magnetic films

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Keywords: nanomagnetism, all-optical switching, magnetic recording, micromagnetics

Summary

The ultra-fast control of the magnetization dynamics is of a great interest for fundamental physics understanding and applications. Recent experiments demonstrated the possibility of magnetization switching in ferri- and ferro-magnetic materials using circular polarized femtosecond laser pulses [1,2]. Particularly interesting results were about all-optical switching in segregated granular FePt media [2], which are considered as candidates for heat assisted magnetic recording (HAMR). All-optical (without a magnetic field) switching of FePt media with over 50 kOe zero-temperature anisotropy field was demonstrated, including control by the sense of the circularly polarized light. Currently there is no clear understanding of the fundamental physics behind these experiments.

Here, we present formulations to model all-optical switching in granular FePt media. The media are composed of FePt L10 single domain weakly exchange-coupled grains. The switching includes short (fs) and longer (ps and ns) time scales. The short time scale effects combine a direct optical effect generated by the interaction between the polarized light and electrons as well as ultrafast thermal demagnetization. The direct optical effect can be explained by inverse
Faraday effect but very strong Faraday fields need to be involved. Alternatively, a three-level optical pumping model can be introduced to explain the direct optical effect. The longer time scale effects are due to thermal demagnetization and grain interaction.

Media with a large number of grains are considered correspond to realistic FePt media. Comparisons of the simulation model and experimental results are conducted. The study includes the simulation of the short and long timescale effects using micromagnetics. The considered parameters include optical pulse lengths and strengths, polarization sense, presence or absence of a DC magnetic field, effects of short and long time scales, effects of grain interactions, and effects of heat sink and cool-down rates. Comparisons between different models are presented.

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**References**

Orientation effects in structural and electronic properties of anatase TiO$_2$ nanowires and nanotubes

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Keywords: nanowires, nanotubes, electronic properties

Summary

By means of *ab initio* calculations we have revealed the existence of sizable anisotropy in electronic properties of anatase TiO$_2$ nanowires with respect to orientation: nanowires with <001>, <100> and <110> axes are found to be direct band-gap, indirect band-gap and degenerate semiconductor materials, respectively. The degenerate semiconducting properties of <110>-oriented TiO$_2$ nanowires are predicted to be an intrinsic feature closely connected with stoichiometry. It is also shown a band-gap variation with nanowire diameter to display rather complex behavior characterized by a competition between quantum confinement and surface states effects that is fully compatible with available contradictory experimental data. Finally, a model to explain the band-gap variation with size in TiO$_2$ nanowires, nanocrystals and thin films is proposed. In addition, we present results indicating crucial changes in morphology of anatase TiO$_2$ nanotubes originated from TiO$_2$ nanowires by making a hole along the wire axis. The critical wall thickness has

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been found to exist for the nanotubes with <001> and <110> axes: at smaller thickness their shape can be rounded, squeezed, viewed as conglomerates of nanocrystals and even represented as cylindrical and ’single-walled’-like structures formed without rolling up a thin titania layer into a nanotube. In general, band dispersion near the gap region of TiO$_2$ nanotubes are close to the one of TiO$_2$ nanowires with the same orientation. We have also revealed that optimization of the unit cell parameter along the wire axis and consideration of quantum confinement and surface states effects are important to provide an interpretation of band-gap variation with respect to wall thickness in TiO$_2$ nanotubes.
Fundamental and Applied Electromagnetics

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New method for determination of refractive index of biomolecule solution by the photonic crystal application.

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Keywords: biomolecules, DNA, glycine, tryptophan, photonic crystal, effective reflective index, absorption spectra.

Summary

Photonic crystals (PC) are of great interest for optics, optoelectronics and sensor applications [1] due to their potential in the control of the propagation and the emission of light. While light interference in the 1D and 2D periodical structures causes just formation of minima and maxima in light illuminance, interference in the 3D opal structure can result in the so-called photonic band gap, i.e. completely forbidden propagation of light over certain range of frequencies [2, 3]. The existence of the photonic band gap influences the optical properties of both the PC as well as atoms and molecules inserted in the cavities of the PC. An infiltration of biomolecules in PC results in modifications of the optical properties (refractive index) molecules.

Here we present data on study of PC infiltrated by biological molecules – DNA, glycine (Gly) and tryptophan (Trp). Transmission spectra of PC infiltrated of water and PC infiltrated by aqueous solution of DNA, Gly and Trp have been studied for determination of reflective index of biomolecules. Effective refractive index can be calculated using a
modified Bragg law, which describes a relation between local maximum in the reflectance spectrum $\lambda_{\text{max}}$, corresponding angle $\theta$ of light detection, size of globules $D$, effective refractive index $n_{\text{eff}}$:

$$\lambda_{\text{max}} = 2\sqrt{\frac{2}{3}} D \sqrt{n_{\text{eff}}^2 (\lambda) - \sin^2 \theta}.$$  This model assumes that the refractive index of a composite mixture is an average of the indices of components weighted by their corresponding volumes:

$$n_{\text{eff}} = n_{\text{globule}} (\lambda) \cdot f + n_{\text{inf}} \cdot (1 - f),$$

where $n_{\text{globule}}$ is a refractive index of silica, $n_{\text{inf}}$ is a refractive index of the substance contained in the pores of photonic crystal, and $f$ is the volume fraction of globules in the sample ($f=0.74$ for dense hexagonal packing).

We estimated a refractive index of biological molecules (concentration 1 mg/ml) infiltrated in PC by shift of frequency comparing the transmission spectra of PC infiltrated by water and PC infiltrated by molecule aqueous solutions. Refractive index of aqueous solution of DNA, Gly and Trp have been calculated to equaled to 1,28; 1,39 and 1.36, correspondently, in contrast to refractometer method, in which we got refractive index equaled to 1.33 for all above mentioned molecule solutions.

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**References**

Broadband electromagnetic characterization of ternary polypropylene-MWCNT-clay composites

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Keywords: carbon nanotubes, electromagnetic response, composites

Summary

In the present study results of broadband measurements of electromagnetic response of composite materials based on multiwall carbon nanotubes (MWCNTs), clay and polypropylene matrix in low frequency (100Hz-1MHz), microwave (26-37 GHz) and terahertz (0.5-3.5 THz) regions are presented.

The obtained results are from the one hand in good agreement with previous investigation of bi-filler systems based on MWCNTs in dielectric matrix [1-3]. From the other hand it was ascertained that adding of third component (clay) may improve dispersion of nanocarbon filler in polymer matrix and significantly affect the electromagnetic response of obtained composite material.

The effects related to the influence of clay on electromagnetic properties of composites with concentration of MWCNTs both above and below percolation threshold are discussed.

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References


Synthesis and electrical properties nanocomposites of epoxy resin with nanocarbon filler

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Keywords: electrical properties, nanocomposite, graphene, epoxy resin.

Summary

Nanocomposites are nowadays one of the most promising materials. Among different fillers, e.g. carbon nanotubes and silicon carbide nanowires (NWSiC), already used with epoxy resin matrices, graphene exfoliated graphite (EG) and graphene nanoplates have some characteristics that make them unique for electromagnetic shielding materials. However, there is still an unresolved problem of proper dispersion that will ensure the homogeneity of samples. To overcome this drawback, inorganic fibres were proposed. An amount of 0.25 phr (parts per hundred; filler content presented as wt.% of the whole polymeric matrix) NWSiC, added to the EG 1 phr/epoxy resin sample, efficiently prevents filler agglomeration. NWSiC were obtained in combustion synthesis and EG was produced from intercalated graphite using microwaves. Finally, nanocomposites with EG from self-propagating high-temperature synthesis were also tested. The properties of the samples have been characterized, revealing an observable improvement of pure resin features. Raw products of combustion synthesis of Si/polytetra-fluoroethylene (PTFE) stoichiometric mixture, carried out in the larger of the presented reactors.
Figure 1. The electrical properties of composite with MWCNT and GNP

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Electromagnetic properties of nanohelices

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Keywords: nanohelices, molecular electronics, photogalvanic effect

Summary

Man-made nanohelices have been recently realized by several different growth and fabrication techniques [1, 2]. Already there is progress in potential applications, and even the double helix of DNA itself has been shown to be promising for molecular electronics [3, 4]. It has been shown that the helical motion of electrons subjected to a transverse electric field in chiral carbon nanotubes can give rise to superlattice properties such as Bragg scattering [5, 6]. In this work, we show how Bloch oscillations [7], leading to negative differential conductance, and the quantum cascade phenomena [8] may arise in our considered nanohelix system, shown in Fig. 1. Furthermore, we consider dipole transitions across the energy gap opened up by the transverse electric field, and show how a novel photogalvanic effect arises from shining circularly polarized light along the axis of the helix.

We have calculated the current-voltage characteristic of the nanohelix, accounting for scattering with the Tsu-Esaki formula [7]. For higher applied voltages, effects such as Zener tunneling between the first and ground band should be taken into account, which we treat within the WKB approximation. This results in a current-voltage characteristic of the so-called ‘N-type’, similar to tunnel diodes [9]. Thus, it is conceivable that nanohelices could be important for device physics, as high-frequency amplifiers and generators. Bloch oscillations at the mini-zone boundary will occur at a terahertz frequency 1.5 THz for nanohelices of pitch 10 nm and applied parallel field $E_\parallel = 103$ V/cm, suggesting nanohelices as a useful commodity to resolve outstanding
challenges in terahertz optoelectronics. We also show that subjecting a nanohelix to a very strong electric field leads to the Stark ladder and quantum cascade phenomena [8].

We have calculated the matrix elements of dipole transitions for linearly polarized excitation as well as for circularly polarized light propagating along the helix axis. For linearly polarized light with polarization normal to the axis the dipole matrix element strongly depends on the angle between the light polarization plane and the external DC electric field. This is similar to an Aharonov-Bohm ring in an electric field [10] but has the advantage that a strong magnetic field is not required. For the light polarized along the helix axis the transitions are strongly enhanced near the miniband extrema. As expected, the circularly polarized excitation induces in the nanohelix a photogalvanic effect, which is suppressed for the transitions across the electric-field induced gaps or in the strong transverse field altogether.

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**References**

Mechanical properties at nanoscale of PMMA/graphene films

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Keywords: graphene, thin films, nanocomposites

Summary

Graphene is predicted to have remarkable properties, such as high thermal conductivity, superior mechanical properties and excellent electronic transport. The intrinsic properties of graphene have generated enormous interest of researchers for its possible implementation in different devices. Graphene is an interesting material from the point of view of electromagnetic shielding. As nanofiller, graphene may be preferred over other conventional nanofillers owing to high surface area, aspect ratio, thermal conductivity and electrical conductivity, high elastic modulus, flexibility, and transparency.

In this work we study mechanical properties at nanoscale of graphene combined with poly(methyl methacrylate) (PMMA). Sandwich structures composed of PMMA/graphene multilayers were produced, where graphene monolayer is synthesized by chemical vapor deposition (CVD) at 1000 °C in methane atmosphere on copper catalyst and then spin coated with 600-800 nm thick PMMA layer, as described elsewhere [1].

The reinforcing effect of graphene in PMMA/graphene films was investigated using advanced methods of nanoindentation, nanoscratch,
and mechanical deformation in bending mode [2]. Nano-, micro- and macro-mechanical properties including stiffness, toughness, hardness, scratch and adhesion of multilayered samples were investigated and compared with the properties of the neat PMMA layer. Quantitative scratch characteristics including coefficient of friction were evaluated in order to determine the adhesion between graphene/polymer layers and the adhesion of the multilayer film on the substrate.

The reinforcement effect of graphene in the multilayer films was analyzed based on the enhanced mechanical properties at micro and nanoscale.

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Synthesis and magnetic properties of dispersed nickel ferrite obtained by glow discharge in system Fe$^{2+}$--Ni$^{2+}$--SO$_4^{2-}$--OH$^-$$^1$

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Keywords: glow discharge plasma, nickel ferrite, specific magnetization, coercive force

Summary

Nowadays a lot of attention is paid to the development of nanotechnology, nano-formation processes. Among the most promising methods of using electrical discharges, there’s one based on non-equilibrium glow discharge (GD) plasma of reduced pressure contact influence on the disperse environment. Numerous studies have shown that aqueous solutions non-equilibrium plasma treatment causes oxidation and reduction of solution components. Thus, metal ions oxidize and form insoluble or sparingly soluble compounds. The aim of this work was to study the effect of GD on the structure and nickel ferrite magnetic properties. To carry out the task samples were synthesized under different conditions: nickel and iron hydro complex slurry, salt solutions separately, salts of nickel ferrite solutions mixture. Synthesis conditions were varied so that it was possible to find the mechanism of glow discharge ferritization effect. Solutions and sols processing was performed with a help of laboratory setup. Reactor features and its operating principle are described in previous papers. Thought all experiments plasma discharge electrical parameters maintained constant and were as follows: $U=550-600$ B, $I=100-120$mA. The obtained GD precipitates were thoroughly washed with distilled water. They were further dried at 180C to constant weight. Cation
content in the obtained samples was measured by means of complexometric titration methods. To study the transformations occurring during resulting powders heating, we used the method of differential thermal analysis (DTA) and differential thermogravimetric analysis (DTGA). Ferrite powders morphology and their size were studied with a help of scanning electron microscopy. Phase composition (XRD) and ferrite samples structure study was carried out with a help of X-ray diffractometer DRON-2 in monochromatic Cu-Kα- radiation. Crystallite size and microstrain degree index calculation was performed by approximation method. Samples magnetic properties were studied with vibrating magnetometer. Cyclic relation of specific magnetization to magnetic field intensity was based on the experimental results. On the basis of the relations specific magnetization limit $\sigma_{rs}$ and the coercive force $H_c$ indexes were calculated. We also studied ferrite structure transformation processes under the temperature of 25-1000°C as well as determined synthesis conditions influence on the phase composition of the products. DTA, thermogravimetry, X-ray analysis show that glow discharge influence forms nickel ferrite with different crystallinity degrees and lattice parameters. Iron salt and nickel solution glow discharge processing does not change nickel ferrite structure and magnetic properties. Iron and nickel hydroxo- polymer suspensions processing increases the rate of the maximum specific magnetization, coercive force and significantly changes its structure.

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Time and energy dependent wave packet dynamical simulations for carbon nanostructures

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Keywords: carbon nanostructures, graphene computational quantum mechanics

Summary

Wave packet dynamics is\textsuperscript{1} an efficient method of computational quantum mechanics. Understanding the dynamics of electrons in nanostructures is important in both interpreting measurements on the nano-scale and for designing nanoelectronics devices. The time dependent dynamics is available through the solution of the time dependent Schrödinger equation. The energy dependent dynamics can be calculated by the application of the time-energy Fourier transform. We performed such calculations for various sp\textsuperscript{2} carbon nanosystems,
e.g. graphene grain boundaries\textsuperscript{2} and nanotube networks\textsuperscript{3}. We identified the global- and local structural properties of the system which influence the transport properties, such as the structures, sizes, and relative angles of the translation periodic parts, and the microstructure of the interfaces between them.

**Acknowledgements.** This work was supported in part by PIRSES-2012-318617 FAEMCAR.

**References**

**Carbon nanotubes visualization in living cells by means of confocal Raman microscopy**

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**Keywords**: carbon nanotubes, confocal Raman microscopy, glioma cells.

**Summary**

Carbon nanotubes (CNTs) are considered as one of the most promising nanomaterials for various medical applications nowadays [1]. Significant interest in CNTs is based on their unique physical, chemical and biological properties. At present, single-walled (SWCNTs) and multi-walled (MWCNTs) carbon nanotubes applications such as drug delivery, directed intracellular localization of CNTs, photothermal cancer cells ablation, and non-labeling visualization of cancer cells or cancer cells organelles are actively discussed [2]. In present study by means of confocal Raman microscopy SWCNTs of 100-200 nm length were shown to penetrate rat glioma cells C6 plasma membrane, to distribute unevenly into cell cytoplasm, forming small agglomerates of micrometer size, but not to transfer into cells nuclei. Intensive peaks in single-walled CNTs Raman spectra allowed simultaneous visualization of CNT conjugates formation in living cells and cell organelles using commercial fluorescent dye JC-1, avoiding the procedure of cells fixation. Double-peak fluorescence of JC-1, exited by 473 nm laser, and Raman spectra, obtained using 785 nm laser, permitted to reveal, that CNTs caused slight hyperpolarization of inner mitochondria membrane,
intensification of mitochondria fusion, and were localized predominantly near highly energized mitochondria in C6 cells after 72 h of cultivation in the presence of CNTs. Thus, confocal Raman microscopy is a promising effective and non-destructive method for investigation of CNTs biological and medical applications.

Acknowledgements. This work was supported by Students Grant of Belarusian State University

References

Nickel-carbon nanocomposite: a dependence of the morphology on temperature and time of the solid-state pyrolysis

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Keywords: solid-phase pyrolysis, nickel nanoparticles, metal-carbon nanocomposites

Summary

Nickel-carbon nanocomposites have been synthesized by the method of the solid-phase pyrolysis of metal-phthalocyanines at temperatures in the range 600 - 1000°C and synthesis duration time up to 300 min. Nickel nanoparticles of various size have been obtained, which are embedded in carbon nanotubes (CNT), nanofibers and encapsulated in the graphite-like shell. A formation of mutually-graded metallic particles with diameters in the range 5–20 nm takes place at pyrolysis temperatures lower than 700 °C. The temperature of ~700 °C is a threshold for the beginning of the CNTs growth. At these temperatures, the CNTs have diameters ~20 nm and the aspect ratio ~100. A rise of the pyrolysis temperature leads to the increase of the CNTs average diameters. A rise of the synthesis time influences growth of individual CNTs, which leads to an increase of medium diameters and a significant dispersion of the lateral dimension values. An analysis of the growth mechanisms of the metal-carbon nanocomposites has made it possible to determine that the CNT formation is caused by catalytic properties of nickel. In the process of its interaction with
amorphous carbon at high temperatures, Ni forms around itself the graphitized regions with a realization of the cover growth mechanism.

**Acknowledgements.** This work was supported in frames of the collaborative research project of the State Committee on Science of the Ministry of Education and Science of Armenia and the Belarusian Republican Foundation for Fundamental Research No. Ф12АРМ-020.
Multi-branched carbon nanostructures

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Keywords: multi-branched carbon nanotube, laser ablation

Summary

A method is proposed for the synthesis of multi-branched carbon nanotubes. The Y-, X- and star-shaped carbon nanostructures have been fabricated. Such nanostructures are very promising as basic elements for the design of functional logical elements.

The method utilizes the originally designed «Tesla» reactor that allows stable synthesis of differently configured nanostructures of different types. The developed technology of the catalysis process in the «Tesla» reactor give an opportunity to control geometric and physical parameters of the resultant carbon nanostructures. Powerful argon laser is used in the technology proposed.
The control of morphology of a carbon nanocomposite by means of the change of metal nanoparticles concentration

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Keywords: solid-phase pyrolysis, metal nanoparticles, carbon nanocrystallites

Summary

Metal-carbon nanocomposites with various concentration of metal (0 ≤ c ≤ 3) have been synthesized by the method of the solid-phase pyrolysis of the solid solutions of a metal-free-phthalocyanine and a copper-phthalocyanine. Carbon microspheres consisting of the amorphous carbon and graphite-like carbon nanocrystallites were obtained at c=0. It has been shown that the growth mechanisms of carbon nanostructures can be controlled by the change of metal concentration in nanocomposites. In this way, at the low metal concentration (0 < c ≤ 1) the carbon microspheres with intercalated metallic nanoparticles are formed. At the larger metal concentrations (2 ≤ c ≤ 3) the microspheres are destroyed and compact carbon “plates” with engrafted copper nanoparticles are developed. These microspheres are in its turn encapsulated by the graphite-like carbon. A mixed state of the both phases is obtained at medium metal concentration (1 < c < 2).

Acknowledgements. This work was supported in frames of the collaborative research project of the State Committee on Science of the Ministry of Education and Science of of Armenia and the Belarusian Republican Foundation for Fundamental Research No. Φ12APM-020.
Structural and mechanical properties of epoxy resins nanocomposites loaded with carbon nanostructures

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Keywords: nanocomposite, nanocarbon, epoxy resin

Summary

The influence of multiwalled carbon nanotubes and graphene nanoplates on the structural and the mechanical properties of an epoxy resin composite is investigated. The obtained nanocomposites and the pure epoxy resin were characterized through solid state NMR (ss-NMR) spectroscopy and tests of nanoindentation. The analysis shows that fillers do not obstruct reticulation of resin, but improve mechanical properties of epoxy resin. The use of ss-NMR and nanoindentation techniques allowed to combine and compare complementary information in order to obtain a complete characterization of the investigated systems.
Figure 1. Concentration dependence of nanohardness (left) and Young’s modulus (right) of epoxy resin with multi-walled nanotubes and graphene platelets as fillers.

Acknowledgements. This research was funded by EU FP7 projects FP7-318617 FAEMCAR and FP7-610875 NAmiceMC. NMR experimental data were provided by Centro Grandi Apparecchiature - UniNetLab - Università di Palermo funded by P.O.R. Sicilia 2000-2006, Misura 3.15. We would thank Asbury Carbons to provide us expandable graphite for our experiment.
Microstrip DC electrical characterization of graphene nanoplatelets

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Keywords: Graphene, Conductivity

Summary

In the last years a large number of researchers have focused their attention and activity on solving problem of Copper miniaturization limitations. The increasing of frequencies and reduction of the electronics unit arise the their heating due to Joule effect. For these reasons, low-dimensional carbon nanomaterials, in particular carbon nanotube (CNT) and Graphene have attracted much attention for their wide applicability in 3-D ICs, as a result of their extraordinary electrical, thermal, and mechanical properties. In particular, the outstanding electrical, thermal and mechanical of graphene make this innovative material a serious candidate to replace conventional metals in nano-interconnects and open the era of so-called carbon electronics [1, 2]. Since 2004 graphene has arisen in number of studies as a wonderful carbon materials for interconnections and THz applications. Graphene-based interconnects have been studied by means of more and more accurate models [3, 5]. At beginning of our work we decide to start studying what is done at moment on analysis of electronic properties of Gaphene, mainly to realize testing set up to validate the modelling prediction. In the same time we have made graphene by own technique, cheaper and faster than other, and to identify a configuration to make
the measurements. In the modelling of electrical property of Graphene is necessary to contemplate as parameters, presence of defects and external impurities in the potential polycrystalline nature of the graphene they can affect its properties. In general, the conductivity of graphene is very frequency-dependent, and can have completed different behaviour e.g. at microwave and THz [6]. For this work we’ve used Graphene Nano-plates (GNPs), they were integrated into the micro-strip circuit to measure the wonderful electrical properties. GNPs are a few layers of Graphene, 11 – 1 layer normally, with an area between 2 -10 µm. They were obtained by microwave irradiation of Graphite Intercalated Compound (GIC), by Asbury®, used as carbon source: GIC was put in home microwave oven, at power of 800W, inside a ceramic melting pot. About ten seconds of irradiation are enough to produce Expanded Graphite (EG) in form of worm-like particles: the process of expansion was carried out by thermal shock due to microwave irradiation and vaporize molecules present inside EG planes.

They are dropped on surface of electric circuit and we carried out electrical measurement in DC, their analysis is under processing..

References

Terahertz-to-infrared converter based on CuNi nanoparticles

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Keywords: THz-to-IR converter, THz medical imaging, early cancer detection, CuNi nanoparticle

Summary

This study is devoted to assessments of designing possibilities of the terahertz (THz) medical imaging instrument for the early cancer detection. Contemporary achievements in clarification of interaction details of the THz radiation with biological tissues, progress in development of the THz optics and high-sensitive infrared (IR) cameras, as well as better understanding the THz absorption in metal nanoparticles make it possible designing the THz medical imaging instrument built around the IR camera using the THz-to-IR converter based on bimetallic CuNi nanoparticles. A special attention of our study is dedicated to the THz-to-IR converter because, to the best of our knowledge, until recently, such instruments were not commercially available.

THz radiation is sensitive to water, which is one of the most important components of the biological tissue. Water molecules absorb all the frequencies in the THz band. There is difference in the water content between healthy tissues and cancerous tumors that result in different THz absorption. We assume that the tumor can shield the intrinsic THz radiation of the patient’s body forming a silhouette and therefore it could be imaged in vivo. To increase image contrast from healthy and pathological tissue areas, contrast agents can be used. In such approach, the cancer cells are probed with nanoparticles and then
are irradiated with near-infrared laser beams. In consequence, the hyperthermia effect occurs due to surface plasmons excited in nanoparticles and hence, the temperature of water in the cancer cells is increased. Since the THz radiation is sensitive to water temperature variations, the tumor can be visualized.

Advances in THz optics and commercial availability of the IR thermal imaging cameras with thermal sensitivities of 14 to 50 mK allow to propose a way for THz medical imaging. In this way, the THz objective forms the image of the patient’s body fragment with the tumor on a two-dimensional THz radiation-to-heat converter mounted on the back of the heat filter cutting off the IR radiation of the patient’s body. The converter represents a matrix of the material transparent in THz and IR rays, with a lot of embedded metal nanoparticles isolated from each other. Nanoparticles being heated by the THz radiation, convert the THz energy to heat, while the two-dimensional pattern formed by heated nanoparticles is visualized by the IR camera.

As nanoconverters in the matrix, the CuNi nanoparticles could be used due to enhanced density of electron states at the Fermi level in copper-nickel alloys, which increases the conversion efficiency of nanoparticles. Estimations show that the CuNi nanoparticles to be well heated should have diameters within a range from 1.6 to 3 nm. Heating of every nanoparticle is thought to consist of two consecutive processes: first, the Fermi electron absorbs simultaneously the THz photon and the longitudinal acoustic vibrational mode (LAVM) available in the nanoparticle; hereafter the excited electron is scattered on the nanoparticle’s boundary exciting a LAVM with the energy higher than that of the previously absorbed LAVM. As a result, the nanoparticle is heated. This THz imaging instrument could enable both the imaging in transition (for in vitro studies) and reflection geometry (for in vitro and in vivo imaging). Besides, a reflection-mode THz imaging accompanied by a NIR laser for the surface plasmon excitation could be realized.

References

Mechanical and electromagnetic properties of polypropylene composites with carbon nanotubes and clay

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Keywords: carbon nanotube, electromagnetic properties, composites

Summary

Polymer nanocomposites with carbon nanotubes are widely studied and significant improvement of mechanical properties [1,2] combined with novel physical properties of composites are reported. Recently hybrid polymer nanocomposites incorporating carbon nanotubes and clay nanofillers are attracting our research interests as a possible approach for achieving the multi-scale reinforcements and multifunctionality.

In the present study we investigate the multi-scale reinforcement effects of bi-filler systems, based on isotactic polypropylene (iPP) incorporating multiwall carbon nanotubes (MWCNTs) with increasing content of 0.5-5 wt.% and fixed amount of 3 wt. % organo-clay in the presence of compatibiliser (MAgPP). The composites were produced by melt mixing process in double screw extruder. Mechanical and microwave properties of mono-filler PP/MWCNT and bi-filler PP/MWCNT/Clay composites are characterized and the effects of filler contents and filler combinations on the composite properties are discussed.
Nanoindentation test is applied and the generated load versus displacement data are analyzed for the test specimens. Tensile tests were conducted using universal mechanical testing device UMT-2 (Bruker). The effect of MWCNTs on the mechanical properties improvement, as varying the nanofiller content, is strongly dependent on the structure formed by nanotubes in the polymer. For the nanocomposites studied, we have identified three zones of mechanical improvement: “nucleation zone” (0-1wt% MWCNTs); “flocculation zone” (1-4wt% MWCNTs); and “percolation zone” (above 4wt% MWCNTs). The bi-filler system show better reinforcement effect in the percolation zone.

The electromagnetic (EM) response of samples as ratios of transmitted /input and reflected /input signals was measured within 26–37 GHz frequency range. Both mono-filler PP/MWCNT and bi-filler PP/MWCNT/Clay systems shows considerable electromagnetic shielding efficiency at small layer thickness of 0.5-1.5 mm by increasing the contents of the MWCNTs. Thus at 3 wt% MWCNTs ~ 80% of EM attenuation is obtained due to 30% Absorption and 50% Reflection of microwave power, with only 20% transmission of microwaves.

Generally, the effect of the clay addition on the EM shielding efficiency is insufficient, while the content of MWCNTs is a determinant factor.

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References

Graphene nano platelets / epoxy composites in wide frequency and temperature range

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Keywords: Graphene, composite, dielectric properties, thermal properties, redistribution, annealing

Summary

We report on an experimental study of composite materials based on graphene nano platelets (GNP) dispersed in nonconductive epoxy resin matrix. GNP were obtained by microcleavage exfoliation of expanded graphite. Dielectric properties where studied in wide frequency (from 20 Hz to 2 THz) and temperature (from 25 K to 600 K) ranges.

Broadband dielectric spectroscopy of composites at room temperature demonstrates that percolation threshold in such systems is 2.87 wt. % of GNP [1]. Above percolation both dielectric permittivity and conductivity of samples is very high (higher than 300 and 0.02 S/m at 129 Hz, correspondingly). At high temperature region (above room temperature) samples with small concentrations (0.25 and 1 wt. %) demonstrate Arrhenius dependence of conductivity and has small hysteresis on heating and cooling cycles. Samples with higher concentrations (2, 3, and 4 wt. %) has huge hysteresis during first annealing and their conductivity increases up to 6 orders of magnitude. This phenomenon can be understood with employing impedance
formalism. During heating Maxwell-Wagner relaxation time shifts down to 3 orders of magnitude and remains on the same position on cooling. We can conclude that during annealing due to redistribution of GNP particles [2,3], huge GNP conductive clusters divides into smaller (that corresponds to decreasing of relaxation time).

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**References**

Optical properties of thin pyrolytic carbon films versus graphene layers

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Keywords: pyrolytic carbon films, graphite, graphene layers, optical properties.

Summary

Carbon materials are recently attracting ever growing attention of the research community due to their strong potential in electronics, optics, medicine etc. Carbon can exist in several allotropic forms such as crystalline forms - diamond, graphite, graphene and molecular forms for example - fullerenes, pyrolytic carbon and carbon nanotubes[1]. Much less attention was paid to electronic and optical properties of pyrolytic carbon (PyC), which is composed of disordered and intertwined few layer graphene flakes with size of several nanometers [2,6]. Pyrolytic carbon is formed by pyrolysis of a hydrocarbon gas resulting in random crystallization of material. So, the final film has layered distorted lattice structure with a lot of defects [3]. Optical applications of pyrolytic carbon are not very common. But sometimes we can meet very amazing examples. Pyrolytic carbon is diamagnetic material. So it can levitate in especially configurable magnetic field.
Recently Japanese scientists successfully modified magnetic susceptibility of pyrolytic carbon sample by laser light [4]. So, they obtained an interesting example of transformation light energy directly to motion. We have studied optical properties of pyrolytic carbon films with thickness 5, 8 and 20 nm deposited by CVD method, and compare them with graphene layers and graphite. Scanning electron microscopy testifies that we have material which is much denser than graphene. According to atomic force microscopy data the films have granular structure. The grain size is below 100 nm. Light absorption spectra of carbon materials usually contain band at 270 nm which is caused by $\pi-\pi^*$ and $\sigma-\sigma^*$ electronic transitions inside carbon rings. Light absorption in graphene is unique because it is defined by fine-structure constant. This constant [6] defines quantum-mechanical reasons for fine-structuring spectral lines. So, graphene can be the bridge between classical optics and quantum mechanics. Optical measurements were made with a DMR-4 spectrophotometer in the 360–1100 nm wavelength range. Reflectance and transmittance spectra were recorded for $p$-polarized light at several angles of incidence. Optical properties of pyrolytic carbon films in the visible spectral range have been studied with reflectance/transmittance spectroscopy. We have shown that refractive index and absorption coefficient of the present PyC films deposited on silica substrate are quite similar to those obtained for graphite and graphene. However atomic force and surface electron microscopy investigations have shown that films possess granular morphology and rough surface that should be taken into account in future experiments.

Acknowledgements. This work was partially supported by EU FP7 project FP7-318617 FAEMCAR.

References

Wave packet scattering through randomly distributed nitrogen dopant area in graphene

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Keywords: graphene, wavepacket scattering, doping, random distribution

Summary

The propagation of wavepackets have been investigated recently in an ideal graphene monolayer \cite{1,2} in which low-energy electrons obey the Dirac equation for massless fermions \cite{3}. Thus, the experimental isolation of graphene layers was undoubtedly a very important scientific achievement, for it opened the possibility of using electrons in graphene to simulate effects which were supposed to be observed only for relativistic particles. The scattering of Schrödinger and Dirac particles by potential and magnetic barriers has also been subject of recent studies \cite{4}, where, for solving the time-dependent Schrödinger and Dirac equation, a numerical method based on the split-operator technique \cite{5} was used. Later on using the same technique we investigated the propagation of wavepacket in a graphene monolayer with a random potential landscape \cite{6}.

In this work we investigate the propagation of wavepackets in a graphene monolayer containing a random distribution of nitrogen dopants. As an initial state, a Gaussian type wavepacket was considered. The equation of motion of the wavepacket was solved using the split-
operator technique [4-6], to see how the set of impurities influences the electron transport properties of the graphene sample.

References

Jagged graphene nanoribbons: structure, electronic properties and effect of an external electric field

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Keywords: graphene, electronic properties, composites

Summary

Band gap control is useful for optical, infrared and THz devices emitting and detecting radiation. Therefore, materials with widely adjustable band gaps are in great demand. In nanoscale systems band gap can be readily changed by system modification and an external field application. However, usually this requires a compound of various potentially toxic elements. On the contrary, electronic properties of carbon nanostructures depend on their geometry. Therefore, using the orthogonal tight-binding method for pi-electrons, we have investigated electronic properties and the effect of the external electric field on a subclass of monolayer chevron-type graphene nanoribbons that can be referred to as jagged graphene nanoribbons [1]. A classification of such ribbons was proposed and band gaps for applied fields up to the SiO₂ breakdown strength (1 V/nm) were calculated. According to the tight-binding model, band gap can be finely adjusted by specific choice of the structural parameters of the system. Moreover, opening (or closing) takes place for some type of jagged graphene nanoribbons in the external electric field that lays in the plane of the structure and perpendicular to its longitudinal axis. Tunability of the band gap up to 0.6 eV is attainable for narrow ribbons. In the case of jagged ribbons
with armchair edges larger jags forming a chevron pattern of the ribbon enhance the controllability of the band gap. For jagged ribbons with zigzag and armchair edges regions of linear and quadratic dependence of the band gap on the external electric field can be found that are useful in devices with controllable modulation of the band gap.

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**References**

Electromagnetic properties of exfoliated graphite

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Keywords: electromagnetic (EM) properties, exfoliated graphite.

Summary

We report on the experimental study of electromagnetic (EM) properties of exfoliated graphite (EG) in Ka-band obtained by intercalation of natural graphite flakes, subsequently submitted to a thermal shock. Accordion-like particles were thus produced, leading to a material of low packing density, around 3 g/l. Typically, the diameter of the EG particles is in the range 0.3-0.5 mm, and their aspect ratio is around 20 [1].

A series of composite samples were prepared, based on epoxy resin (Epikote 828), a curing agent called A1 (a modified TEPA) and up to 2.0 wt. % content of exfoliated graphite (EG).

The microwave measurements were provided by scalar network analyzer R2-408R (ELMIKA, Vilnius, Lithuania). The electromagnetic (EM) response of samples as ratios of transmitted/input (S_{21}) and reflected/input (S_{11}) signals has been measured at room temperature in frequency range 26-37 GHz (Ka-band). The average value of power transmitted through the samples is 60%, 30%, and close to 0 for 0.25, 1 and 2 wt.% of EG embedded, respectively. Along with high EM
performance in microwave range, graphene platelets are much more easily processable than composites filled with CNTs.

To conclude, EG could be used for producing very effective thin and lightweight EM material in the Ka-band when the concentration of fillers reaches 2 wt. %, but for this content the mechanical properties started to degrade, which might perhaps be avoided by improving the fabrication process.

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**References**

Controllable growth of silver dendrites in the Si/SiO$_2$ porous templates

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Keywords: porous templates, silver dendrites, surface enhanced Raman scattering, nanostructures

Summary

As a result of the present work, porous templates of the amorphous silicon dioxide layer on silicon substrate are formed by means of the chemical etching of highly-defect areas in the SiO$_2$, formed as a result of the swift heavy ion irradiation. The pore parameters directly depend on the etching time, which make it possible to adjust pores diameter, height and degree of overlap. It has been found that the self-organization process at the rise of metallic dendrites in the limited pore volume is controlled both by the deposition parameters (electrolyte temperature and deposition time), and the change of pore geometry parameters. Preliminary experiments on surface enhanced Raman scattering (SERS) effect on silver dendrites in the pores of SiO$_2$ have been carried out successfully. The possibility of application of the silver dendrites in chemical and biological devices for the identification of the substance microdoses has been demonstrated.
Influence of nanosized barium ferrite particles addition on microwave properties of nanocarbon/polymer composites

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Keywords: barium ferrite, composite materials, shielding

Summary

The presentation is devoted to the investigation of electrodynamic properties of graphite nanoplatelets (GNPs)/epoxy and multiwall carbon nanotubes (MWCNTs)/epoxy composite materials (CMs) and CMs with binary filler where the second filler was dielectric barium hexaferrite (BaFe₁₂O₁₉) nanopowder. The content of MWCNTs (GNPs) in CMs was 2 - 5 wt. %, the content of BaFe₁₂O₁₉ was 30 wt. %. All components are mixed by methods of ultrasonic dispersing. To obtain CMs with aligned barium hexaferrite the composite mixture was placed to the 0,64T magnetic field till the end of the polymerization process. The scalar network analyzer was used to measure the transmission and reflection loss within the 36–55 GHz frequency range. Voltage measurements of the standing wave ratio (SWR) were used to determine the reflection properties (36-55 GHz), morphology and structure were studied through XRD, SEM.

The results of systematic investigation of the influence of a type and content of nanocarbon fillers, the methods of production (under or without magnetic field), polarization of EMI, external magnetic field value on transmission and reflection characteristics of the CMs in the frequency range 36–55 GHz are presented.
It was revealed that for the 30 wt% BaFe$_{12}$O$_{19}$/epoxy samples the transmission and reflection loss are frequency independent. For the samples which were obtained in presence of magnetic fields the peaks of adsorption was appeared at 47-48 GHz the value and position of which were strongly dependent on orientations of the sample in relation to the EM radiation distribution and the value of external magnetic fields. For the samples with binary fillers the essential increase of transmission was observed, but the anisotropy of its value as well as anomalous adsorption at 47-48 GHz were appeared only for the CMs with low concentration of GNP. It was shown that the effect of magnetic field in the process of manufacturing at CNTs containing CMs on the microwave properties is less than on GNPs containing CMs. This may be due to the different mobility of the particles in the composite mixture because of the shape and mass otherness of the nanoparticles.

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