FAEMCAR: FUNDAMENTAL AND APPLIED ELECTROMAGNETICS OF NANOCARBON

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We participate as a partner (the INFN unit) to the PEOPLE MARIE CURIE ACTIONS International Research Staff Exchange SchemeCall: FP7-PEOPLE-2012-IRSES. FAEMCAR has a duration of 48 months and started its activities on 3rd January 2013. The consortium binds together three Universities and four Research Organizations.

Project Achievements in 2015

Scientific highlights and research achievements The FAEMCAR project focuses on four work packages: WP1 Synthesis and fuctionalization of multi-walled CNTs and fabrication of composite materials on the basis of different forms of nanocarbon [7,10,11]; WP2 Electromagnetic response of pure nanocarbons and nanocarbon-based composites in radio, microwave and THz frequency ranges [2,5,8,9,12,13]; WP3 Electromagnetic wave interaction with functionalized nanocarbons. Radio frequency and microwave response of saline CNT solutions [6,7,8]; WP4 Electromagnetics of graphene and graphene-like structures [1,3,4,6,14,15,16,17]. The figures between square brackets […] refer to the papers published during the reporting period and listed here below. Graphical scientific highlights can be found on the web page of the FAEMCAR project (http://www.faemcar.be). Only a few research achievements are outlined herewith. In the frame of WP1, thermostable composite materials based on phosphate binders combine many interesting physical and chemical properties. When loaded with a small fraction of carbon MWNTs, their electrical conductivity increases by several order of magnitudes. Depending on whether the binder is a liquid aluminum phosphate or a solid magnesium phosphate, percolation is achieved with 1.56 or 0.81 wt%, respectively. Electromagnetic measurements across 2-mm thick samples indicate that both phosphate-based composites loaded with 2 wt% MWNT block the transmission of GHz radiations. Regarding WP2, Reticulated carbon foams have been synthesized using polyurethane foams as templates. Combining lightness (50 mg/cm^3, typically) and good electrical conductivity (40 S/m, typically), carbon foams are promising 'green' materials for electromagnetic applications. For instance, the measured shielding effectiveness of a 1.7-mm thick sample reaches 18.5 dB at 30 GHz. Similar results were obtained with tannin-based carbon foams of various densities that were analyzed by broadband dielectric spectroscopy and microwave S-matrix

measurements. In connection with WP3, Epoxy resin composites filled with sono-chemically modified MWCNTs were produced at low concentration, from 0.03 to 0.3 wt.%. Intensive ultrasonic irradiation of the MWNTs dispersed either in liquid epoxy or in the hardener (polyethylene polyamine) was applied to provoke grafting of, respectively, epoxy or polyethylene-polyamine chains to the carbon nanotube surfaces. A significant effect of the amine grafting on the ac conductivity of the composite was observed for such a small concentration as 0.08 wt.%. At 1 kHz, amine-grafted MWCNT led to ac conductivity rise by almost 3 orders of magnitude compared with the conductivity of epoxy-grafted MWCNT composites. Quite a lot of activities have been developed in the frame of WP4 devoted to graphene and similar planar structures. On the experimental side, it has been demonstrated that artificial metamaterials consisting of a few graphene planes alternating with thin PMMA spacers are excellent RF shielding devices, because there is no perturbation of the transport properties of the individual planes induced by proximity effect. Graphene produced by CVD is an interesting RF shielding material, for its DC conductivity is close to the intrinsic admittance of air, ε0c. Indeed, maximum absorption of electromagnetic radiations by a thin conducting sheet occurs when its conductivity in unit of ε0c matches the sum of the refractive indices of the media that line the sheet on both sides. This condition can be achieved by stacking a few layers of graphene. Theoretical developments and computer calculations have later on demonstrated that the optimum absorption of GHz radiations by a graphene/PMMA multilayer is robust against the presence of defects in the graphene layers. This robustness does not depend either on the size of the grains in polycrystalline graphene. In addition, the absorbance and transmittance of the multilayer remain remarkably constant in a wide interval of incidence angle. Finally, the maximum absorbance of the multilayer can be optimized by choosing the thickness and the refractive index of the substrate which holds the multilayer. Unlike graphene, pyrolytic carbon can be produced directly by CVD on a dielectric substrate such as silica. The AFM analysis of pyrolytic crabon grown on silica reveals a rough surface with correlation length less than 100 nm. Pyrolytic carbon is an interesting carbonaceous material for shielding applications, thanks to its good electrical conductivity. In addition, it is relatively transparent in the visible and near infra-red domain (less than 20% absorption for a 5-nm thick film). Optical parameters of pyrolytic carbon with different thickness have been measured by visUV absorption spectroscopy.

Transfer of knowledge and Training activities (workshops)

Transfer of knowledge was realized through the secondment program. This program was particularly useful for early-stage researchers who could be trained in manipulating experimental instruments or using computer codes not available in their home laboratory. In the other way round, experienced visiting researchers could teach young researchers in the visited laboratories. During the reporting period, two workshops have been organized on topics directly related to the FAEMCAR project. The first was a NATO advanced research workshop entitled "Fundamental and applied electromagnetism" (FANEM'15) that hold in the Belorussian State University in Minsk on May 25-27, 2015 (http://www.fanem.org/). About 45 participants from 19 different countries attended the meeting. Among them, ten were researchers directly involved in the FAEMCAR project. A sideline meeting of the FAEMCAR participants was organized during lunch time of the first day. The second workshop worth mentioning here is the "Nanoscience and Nanotechnology meeting" (n&n 2015) organized by INFN in Frascati from September 28 to October 2, 2015 (http://www.lnf.infn.it/conference/nn2015/). A special session on FAEMCAR activities took place on September 29. For both events, the participant could gain a general overview of the last achievements and perspectives of FAEMCAR. This was particularly true for local PhD students involved in the project together with a few others from abroad

who could attend the workshops thank to the mobility program. In so doing, there were trained on different facets of the research.

Dissemination of results (conferences, publications...)

Four international conferences were organized by four FAEMCAR groups during the reporting period. The first two, directly linked to FAEMCAR activities, are described in the above subsection. The other two, respectively organized by the Kyev and Vilnus partners in October 2015, were entitled "Nanobiophysics: fundamental and applied aspects" and "Functional materials and nanotechnology". In both events, there were invited speakers from FAEMCAR, thanks to what both events were sources of dissemination of the results obtained so far. During the reporting period, scientific results obtained by the participant teams in direct relation with the FAEMCAR project have been the published in 17 articles and have preen presented in 27 seminar or invited talks at scientific conferences. The following list of publications contains those with explicit acknowledgment to the project.

Publications by LNF Authors in the Year 2015

Broadband dielectric spectroscopy of composites filled with various carbon materials
S. Bellucci, S. Bistartelli, A. Cataldo, F. Micciula, I. Kranauskaite, J. Macutkevic, J. Banys, N. Volynets, A. Paddubskaya, D. Bychanok, P. Kuzhir, S. Maksimenko, V. Fierro, and A. Celzard, IEEE Transactions on Microwave Theory and Technique 63 (2015) 2024-31.
DOI: 10.1109/TMTT.2015.2418758

Microstructure, elastic and electromagnetic properties of epoxy-graphite composites
S. Bellucci, F. Micciulla, V. M. Levin, Yu. S. Petronyuk, L. A. Chernazatonskii, P. P. Kuzhir, A. G. Paddubskaya, J. Macutkevic, M. V. Pletnev, V. Fierro, and A. Celzard, AIP Advances 5, 067137 (2015).
DOI: 10.1063/1.4922872

Sharp variations in the electronic properties of graphene deposited on the h-BN layer
D.G. Kvashnin, S. Bellucci, and L.A. Chernozatonskii, Phys. Chem. Chem. Phys. A 17 (2015) 4354-9.
DOI: 10.1039/C4CP04660A

List of Conference Talks by LNF Authors in the Year 2015

S. Bellucci (INFN) "Electrical conductivity of graphene: a time-dependent density functional theory study", oral presentation at the NATO Advanced Research Worksop on Fundamental and Applied Nano-Electromagnetics (FANEM'15), Minsk (BY) 25-27/05/2015.