# GRAPHENE: Graphene-Based Revolutions in ICT And Beyond

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We participate to the project Graphene-Based Revolutions in ICT And Beyond, GRAPHENE, Grant agreement number 604391CP-CSA, one of the most important initiatives in the European research. Among participants there are 23 Italian partners including research institutes, universities and enterprises, with 16 new partners including Istituto Nazionale di Fisica Nucleare represented by the NEXT group at LNF, led by Stefano Bellucci. Owing to the new partnerships the consortium binds together more than 140 organizations from 23 Countries, with the common aim of transfering graphene and related composite materials from academic laboratories to everyday applications.

The Graphene Flagship Project represents a European investment of 1 billion euro for the next decade and is part of the Flaghship Initiatives for future emerging technologies (TEF) announced by the European Commission in January 2013. Italy is already a leader in the development of important areas of the Graphene Flagship Project, including research in composite materials and energy applications, and it is involved in technology transfer and dissemination, as well. The participation of INFN is focused on the realization of multi-layered sandwich graphene devices, within the workpackage of high frequency applications. The NEXT group at LNF participates to the work package **WP13 Functional Foams and Coatings, and it is leader of the Task 13.3.6: Nanocomposite coatings for EMI shielding (INFN).**

**Achievements**

We thoroughly investigated the possibility to absorb most (i.e., up to more than 90%) of the incident electro-magnetic radiations in thin multilayered PMMA/graphene structures, thus proposing the technical realization of a device with an operational frequency range in the millimeter-wave domain, i.e., 30 GHz–300 GHz. Our simulations demonstrate the concrete possibility to enhance the field absorption by means of a selective removal and proper micro-pattering within the graphene material, enabling a complete and efficient control of the graphene sheet conductance. This method is applied to design and engineer a class of devices, endowed with a wideband operation capability, showing almost no fluctuations throughout the whole range of mm-wave frequencies.

The high-resolution ultrasonic technique (impulse acoustic microscopy) was applied for observing the bulk microstructure of nanocomposite coatings up to a few mm in thickness, up to a maximum resolution of 1 micrometr in z-axis, with various types of carbon nanoparticles as filler, including graphene nanoflakes, graphene nanoplatelets (GNP). It was shown that ultrasonic methods allowed us to reveal the cluster architecture of the nanoparticle distribution and possible nonuniformity. A pronounced tendency to form micrometer-sized fractal agglomerates was found for 2D carbon nano-particles: nano flakes and nanoplatelets.

Results of broadband dielectric spectroscopy of epoxy resin composites containing GNP have been presented in a wide temperature range (25–500 K). The as-produced composites were heated at temperatures above the epoxy glass transition and subsequently cooled down to room temperature. This annealing was proved to be a simple but powerful process to improve significantly the electromagnetic properties of the GNP-based composites. The dc conductivity of epoxy filled with 4 wt% GNP is 68

times higher after annealing. Another benefit of the annealing is to lower substantially the percolation threshold, from 2.3 wt% for as-produced samples to 1.4 wt%. In composites above the percolation threshold, the electrical conductivity is the result of tunneling between GNP clusters. For a given GNP concentration, the tunnel barrier decreases after annealing.

Among many outstanding properties of carbon-based interconnects, it is of great interest for nanoelectronics applications, the possibility to have an electrical resistance almost insensitive to the temperature increase. This behavior has been theoretically predicted and experimentally proven for graphene nanoribbons, but only in controlled conditions, and for limited ranges of geometrical dimensions and temperature. We demonstrated the possibility of observing such a desirable behavior in graphene conductors, made by self-assembly of graphene flakes.

**Plans**

- Investigation of epoxy resins nanocomposites loaded with carbon nanostructures through solid state NMR and nanoindentation.
- Removal of Non-Aqueous Liquid Phase from aqueous environment by graphene paper.
- Study of bilayer graphene/poly(methyl methacrylate) thin films by THz experimental characterizations; development of and modelling and simulation for the same.
- Study of the consequences of ageing on the electromagnetic shielding properties of epoxy composite loaded with graphene flakes

**Interactions with other WPs, other projects**

Collaboration with WP7 Electronic Devices (Polina Kuzhir)
Interaction with the EU-7th FP projects “NAmiceMC—Nano-thin and micro-sized carbons: Toward electromagnetic compatibility application”, 2014-2017, and “FAEMCAR—Fundamental and Applied Electromagnetics of Nano-Carbons”, 2013-2016.

## List of Conference Talks by LNF Authors in the Year 2016

S. Bellucci, EMI shielding: Graphene materials for electronic and electromagnetic applications, Meeting GRAPHENE Flagship Core 1 - WP13 Task 13.3.6 – Dresden Nov. 3-4., 2016

F. Micciulla, A. Cataldo, S. Bellucci, and A. Maffucci, A Low-Cost Gas Sensor based on a Self-Assembled Graphene Nanoplatelets Contact, 2nd Internal Forum on Research and Technologies for Society and Industry, Technologies for smarter societies, IEEE RTSI, Bologna, Italy, 7-9 Sept. 2016

S. Bellucci "Graphene materials for electronics: microwave-photonic devices (Lecture I and Lecture II", RIAPA-LDS2016 School Tabriz, May 24-25, 2016.

## Publications by LNF Authors in the Year 2016

1. Ballistic Ratchet effect on patterned graphene, S Bellucci, L Pierantoni, D Mencarelli
Integrated Ferroelectrics 176 (1), 28-36 (2016)

2. Defect-induced blue luminescence of hexagonal boron nitride

B Berzina, V Korsaks, L Trinkler, A Sarakovskis, J Grube, S Bellucci
Diamond and Related Materials 68, 131-137 (2016)

3. Innovative tunable microstrip attenuators based on few-layer graphene flakes, M Yasir, M Bozzi, L Perregrini, S Bistarelli, A Cataldo, S Bellucci,
Microwave Symposium (MMS), 2016 16th Mediterranean, 1-4 (2016).

4. Ab initio modelling of dielectric screening and plasmon resonances in extrinsic silicene
CV Gomez, M Pisarra, M Gravina, S Bellucci, A Sindona
Research and Technologies for Society and Industry Leveraging a better r tomorrow (RTSI), 2016 IEEE 2nd International Forum on.

5. A low-cost gas sensor based on a self-assembled graphene nanoplatelets contact
F Micciulla, A Cataldo, S Bellucci, A Maffucci
Research and Technologies for Society and Industry Leveraging a better r tomorrow (RTSI), 2016 IEEE 2nd International Forum on.

6. Efficient and versatile graphene-based multilayers for EM field absorption
D Mencarelli, L Pierantoni, M Stocchi, S Bellucci
Applied Physics Letters 109 (9), 093103 (2016)
.
7. Electrothermal modeling and characterization of carbon interconnects with negative temperature coefficient of the resistance
A Maffucci, F Micciulla, A Cataldo, S Bellucci, G Miano
Signal and Power Integrity (SPI), 2016 IEEE 20th Workshop on, 1-4

8. Bottom-up realization and electrical characterization of a graphene-based device
A Maffucci, F Micciulla, A Cataldo, G Miano, S Bellucci
Nanotechnology 27 (9), 095204 (2016)

9. Plasmon Modes in Extrinsic Graphene: Ab initio Simulations vs Semi-classical Models
A Sindona, M Pisarra, D Mencarelli, L Pierantoni, S Bellucci
Fundamental and Applied Nano-Electromagnetics, 125-144 (2016).