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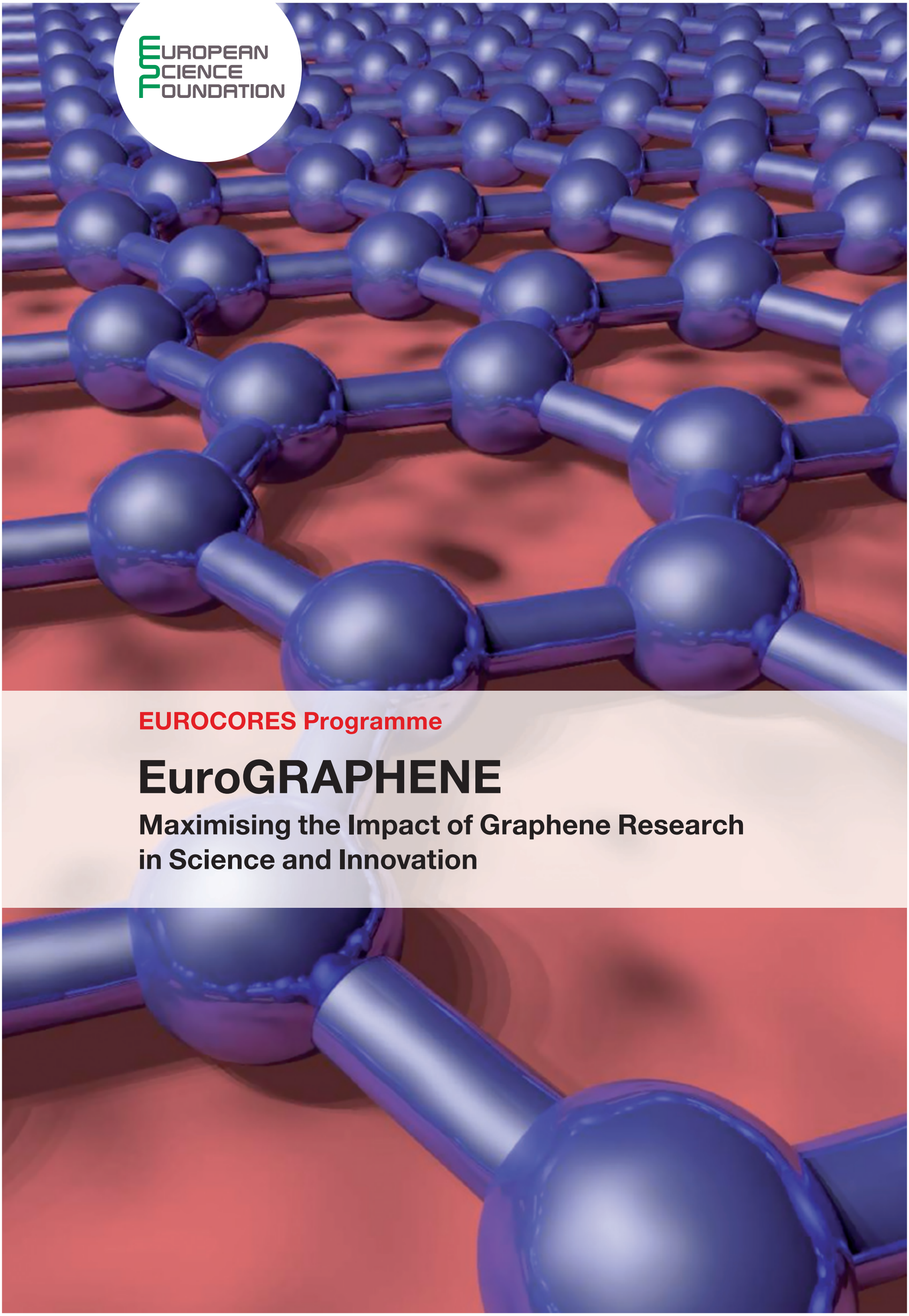

EUROCORES Programme

EuroGRAPHENE

Maximising the Impact of Graphene Research in Science and Innovation

The term graphene stands for a single atomic layer (monolayer graphene) or bilayer of graphite. In graphene, the trend to reduce the dimensions of the conducting elements of electronics has, unexpectedly, led us into a new world of peculiar physical properties, not encountered in standard electronic materials.

Despite being only one atom thick, graphene is chemically and thermally stable, so that graphene-based devices, such as field-effect transistors, have already been manufactured, and they withstand ambient conditions. It has been understood theoretically, and confirmed experimentally, that both monolayer and bilayer graphene are gapless semiconductors, with peculiar properties of charge carriers.

Whereas the interest in graphene as a qualitatively new two-dimensional electronic system boosts the rapid development of the physics of graphene and graphene-based nanostructures, so far the chemical, mechanical, magnetic and other properties of this new material remain unexplored territory.

The EUROCORES Programme EuroGRAPHENE is a three-year programme, which recognises that there is a clear need for European-wide cooperation to tackle the challenges of deepening understanding of the physical properties of graphene; expanding research into new areas of chemical modifications of the material and searching for methods to design its electronic properties; investigating its mechanical and electro-mechanical properties, broadly studying kinetic processes in graphene aiming to understand optoelectronic effects; and modelling graphene-based devices for any functional application.

EuroGRAPHENE will provide the framework for bringing together the complementary expertise of technologists, experimentalists and theorists within small and medium-size consortia of world-leading European research groups. EuroGRAPHENE thus aims to accelerate the pace of European research in graphene and its applications by concentrating and networking the activities.

Collaborative Research Projects (CRPs)

Graphene-Organic SuPramolEcular FunctionaL Composites (GOSPEL)

(ARRS, CNR, DFG, FNRS, SNF)

The aim of this project is the development of new hybrid materials based on the supramolecular interactions of graphene sheets with tailored organic molecules, either small polyaromatics or polymers, for applications in optoelectronics. Different types of molecules (coronenes, perylenes, long alkanes, poly-phenyleneethynylenes, phthalocyanines, etc.) are known to interact with the surface of graphite, forming highly-ordered and stable crystalline monolayers on its surface. The orientation of the molecules on the surface is highly specific (*i.e.*, face-on or edge-on), and even the lateral arrangement of the molecules on the surface can be ordered on nanometric scale. The GOSPEL project aims at exploiting this strong interaction to exfoliate low-cost graphite into graphene sheets, by mixing solutions of organic molecules with suspensions of graphite flakes.

Project Leader:

Dr Vincenzo Palermo
National Research Council (CNR), Institute for Organic Synthesis and Photoreactivity, Bologna, Italy

Principal Investigators:

Dr David Beljonne
Faculté des Sciences, Université de Mons-Hainaut, Belgium

Professor Gvido Bratina
Laboratory for Organic Matter Physics, University of Nova Gorica, Slovenia

Dr Cinzia Casiraghi
Fachbereich Physik, Freie Universität Berlin, Germany

Dr Roman Fasel
Surface Technologies Department, Swiss Federal Laboratories for Materials Testing and Research, Dübendorf, Switzerland

Professor Klaus Müllen
Max-Planck-Institute for Polymer Research, Mainz, Germany

Associated Partner:

Professor Paolo Samorì
Institut de Science et d'Ingénierie Supramoléculaires (ISIS), Université Louis Pasteur, Strasbourg, France

Confinement in Graphene Nanostructures (CONGRAN)

(DFG, FWO)

Until now, quantum dots in graphene have been fabricated exclusively by direct etching of the graphene layer. The dot-lead connections consist of etched graphene nanowires in state-of-the-art devices. Accurate tuning of the dots is difficult due to the disorder in these constrictions which may be edge-induced.
The project will provide a comprehensive picture of possible paths towards definition of highly tunable graphene quantum dots and coupled dots. Electrostatically confined dots in bilayer graphene will be attempted.
The advantages and disadvantages of the different approaches regarding the requirements for various quantum dot experiments will be made clear, and new results regarding spin effects in graphene dots are expected.
The ultimate goal is to demonstrate and exploit the novel scientific possibilities tunable graphene dots offer in comparison to conventional quantum dots defined in semiconductor heterostructures.

Project Leader:

Professor François Peeters
Department of Condensed Matter Physics, University of Antwerp, Belgium

Principal Investigator:

Professor Guido Burkard
Fachbereich Physik, University of Konstanz, Germany

Associated Partners:

Professor Klaus Ensslin
Physics Department, Laboratory of Solid-State Physics, ETH Zürich, Switzerland

Professor Thomas Heinzel
Department of Physics, Faculty of Mathematics and Natural Sciences, University of Düsseldorf, Germany

Professor Lieven Vandersypen
Applied Sciences, Kavli Institute of Nanoscience, Delft University of Technology, The Netherlands

Epitaxial Graphene Transistor (EPIGRAT)

(DFG, GAČR, MNISW, TÜBITAK, VR)

The aim of EPIGRAT is to synthesise and characterise epitaxial graphene layers on silicon carbide suitable for future electronics using different growth techniques, and to develop and characterise high frequency transistors made from these materials. The graphene layers should have an area of several cm^2 and a thickness of one or a few layers fabricated in a controllable way for both polarities of SiC and for various misorientation angles with respect to the c-axis of SiC. Optimisation of graphene growth requires proper pressure and temperature range as well as polytype, polarity and surface preparation of SiC substrates. Interactions of graphene with substrates will be investigated and the growth of graphene on SiC of different polarities will be compared. The project will focus on improving electronic mobility of carriers in graphene – to the level which is obtained in exfoliated graphene. The device part of EPIGRAT will:

- Develop basic fabrication processes and characterisation methods for graphene-based transistors;
- Investigate basic electron characteristics using micro-devices;
- Model graphene transistors;
- Demonstrate microwave monolithic integrated circuits based on graphene transistors; and
- Develop passive components and via-holes (if required) and circuit design.

Project Leader:

Professor Erik Janzén
Department of Physics, Chemistry and Biology, Linköping University, Sweden

Principal Investigators:

Professor Jacek Baranowski
Institute of Electronic Materials Technology, Warsaw, Poland

Professor Detlef Hommel
Experimental Physics in Surface Science, University of Bremen, Germany

Dr Milan Orlita
Institute of Physics, Charles University in Prague, Czech Republic

Professor Ekmel Ozbay
Department of Physics, Bilkent University, Ankara, Turkey

Professor Roman Stepniewski
Institute of Experimental Physics, University of Warsaw, Poland

Professor Herbert Zirath
Department of Microelectronics, Chalmers University of Technology, Göteborg, Sweden

Associated Partner:

Dr Marek Potemski
National Centre for Scientific Research (CNRS), Grenoble High Magnetic Field Laboratory, France

Graphene-based systems for spintronics: Magnetic interactions at the graphene/3d metal interface (SpinGraph)

(CNR, DFG, FWF, SNF)

The unusual electronic structure of graphene gives rise not only to interesting transport properties in the layer of hexagonally coordinated carbon atoms itself, but may also be used to create spin-dependent transport (‘spin filtering’) in graphene-metal contacts sandwich layers. When grown on ferromagnetic substrates such as the perfectly lattice-matched nickel, the overlap of majority and minority charge carriers with the density of states in graphene causes a large spin anisotropy in electron transmission. Similar functionalities may be induced by intercalation of ferro-magnetic materials between graphene and a SiC substrate.
Graphene, grown as a ‘nano-mesh’ on lattice-mismatched metals such as rhodium and iridium, also provides an exciting template for the growth of size-selected ferromagnetic clusters, whose magnetic properties can

then be studied. Since graphene is a truly 2D material, surface-sensitive probes such as Scanning tunnelling microscopy and photoelectron spectroscopy are used in the project to elucidate the structural and electronic properties of graphene, in combination with x-ray magnetic circular dichroism and magneto-optical Kerr effect studies to characterise the magnetic properties. The experimental projects are complemented by theoretical studies of the interface and cluster systems; this is particularly rewarding since both wave-vector-resolved and real space studies of the electronic and magnetic properties are provided by the experimental projects.
As the interaction between graphene and magnetic systems is largely uncharted territory, it is expected that research will provide exciting progress in this field.

Project Leader:

Professor Karsten Horn
Fritz-Haber-Institut der Max-Planck-Gesellschaft, Department of Surface Physics, Berlin, Germany

Dr Yuriy Dedkov (Co-PI)
Fritz-Haber-Institut der Max-Planck-Gesellschaft, Department of Surface Physics, Berlin, Germany

Principal Investigators:

Dr Carlo Carbone
Consiglio Nazionale delle Ricerche, Istituto di Struttura della Materia, Trieste, Italy

Dr Mikhail Fonin
Fachbereich Physik, Universität Konstanz, Konstanz, Germany

Professor Josef Redinger
Centre for Computational Materials Science and Department for General Physics, Vienna University of Technology, Austria

Associated Partner:

Professor Harald Brune
Institute of Condensed Matter Physics, Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland

Graphene on SiC wafers for high performant RF transistors (Graphic-RF)

(CNR, DFG, VR)

This project focuses on transport properties of graphene and its possible application in integrated electronics. In particular, the possibility of growing a few high-quality layers of graphene on SiC will be investigated considering different politypes (4H, 3C), the C and Si face, and different crystal orientations on large diameter wafers (up to 150 mm).
The transport properties will be measured and compared with graphene flakes obtained by other methods such as exfoliation and chemical synthesis with the final aim of investigating the role of defects and interfaces in the transport properties. Both structural (HRTEM, LEEM, ARPA), optical (Raman) and electrical measurements will be used and compared.
The activity will take advantage of the development and implementation of novel nanocharacterisation methods based on scanning probe microscopy able to determine locally (in the mesoscopic limit) transport properties. A multiscale approach to simulate the transport properties will be developed considering atomistic models as well as semi-empirical continuum models.
The possibility of fabricating devices for high speed (frequency) electronics will be investigated, too, considering switching, rectifiers and passive components all based on graphene.

Project Leader:

Dr Vito Raineri
Consiglio Nazionale delle Ricerche, Istituto per la Microelettronica e Microsistemi, Catania, Italy

Dr Antonio La Magna (Co-PI)
Consiglio Nazionale delle Ricerche, Istituto per la Microelettronica e Microsistemi, Catania, Italy

Principal Investigators:

Professor Oleg Pankratov
University of Erlangen-Nürnberg, Erlangen, Germany

Professor Thomas Seyller
Institut für Physik der Kondensierten Materie, Department of Physics, University of Erlangen-Nürnberg, Erlangen, Germany

Professor Rositza Yakimova
Department of Physics, Chemistry and Biology (IFM), Linköping University, Sweden

Associated Partner:
Dr Jean Camassel
CNRS Groupe d'Étude des Semiconducteurs, Université Montpellier 2, France

Electrical and Optoelectronic Graphene Devices (ELOGRAPH)

(DFG, FWF)

The ELOGRAPH project combines experimental knowledge, engineering sciences and theoretical expertise within an interdisciplinary research consortium to realise and to explore the potential of graphene nanoribbon (GNR) devices. The direct band-gap and its tunability GNR-devices makes them promising candidates for future optoelectronic applications (*e.g.*, on-chip optoelectronic data-links or infrared photo-detectors for thermoelectric energy harvesting of residual heat).
This CRP will focus on graphene nanoribbon device fabrication, its optoelectronic characterisation, numerical simulation and modelling as well. First, a novel method to grow graphene layers directly on oxidised silicon substrates will be investigated. This method is based on catalytic chemical vapour deposition (CCVD) and is compatible with state-of-the-art semiconductor processing. Secondly, various physical methods to control the band-gap (*e.g.*, via GNR-width modulation or by creating regular dots or anti-dots on the graphene sheet) will be studied theoretically and experimentally.
Apart from physical methods, the possibility to tune the band-gap of a graphene bilayer by applying a transverse electric field will be investigated in gate-controlled bilayer graphene field effect transistors (FETs). Finally, experimentally embedded modelling of graphene-FETs will be performed in view of integrated circuit design to provide a reliable data basis for future applications.

Project Leader:
Professor Udo Schwalke
Institute for Semiconductor Technology and Nanoelectronics, Technische Universität Darmstadt, Germany

Principal Investigator:
Professor Hans Kosina
Institute for Microelectronics, Vienna University of Technology, Austria

Associated Partners:
Professor Jerzy Katcki
Institute of Electron Technology, Warsaw, Poland
Professor Thomas Zimmer
Laboratoire de l'Intégration du Matériau au Système, Université Bordeaux 1, Talence, France

ENTangled spin pairs in graphene (ENTS)

(AKA, DFG, ETF, FOM, SNF)

Graphene offers truly unique opportunities for spintronics and for quantum information processing. The two major sources of spin decoherence caused by spin-orbit interaction in combination with electron-phonon coupling and hyperfine interaction with the surrounding nuclei are known to be weak.
With the generation of spatially separated entangled pairs of spins in hybrid systems between superconductors and graphene, lots of original possibilities can be envisioned. A successful demonstration of this task would be an experimental breakthrough, facilitating a multitude of quantum information experiments to be performed.

Project Leader:
Professor Pertti Hakonen
Low Temperature Laboratory, Helsinki University of Technology, Espoo, Finland

Principal Investigators:
Dr Jaan Aarik
Institute of Physics, University of Tartu, Estonia
Professor Carlo Beenakker
Instituut-Lorenz for Theoretical Physics, Theoretical Nanophysics Group, Leiden University, The Netherlands
Professor Laurens W. Molenkamp
II-VI MBE Unit, Physikalisches Institut, Lehrstuhl für Experimentelle Physik III, University of Würzburg, Germany

Professor Alberto Morpurgo
Department of Condensed Matter Physics, Faculty of Sciences, University of Geneva, Switzerland

Professor Christian Schoenenberger
Swiss Nanoscience Institute, Nanoelectronics Group at the Department of Physics, University of Basel, Switzerland

Professor Björn Trauzettel
Institut für Theoretische Physik und Astrophysik, Arbeitsgruppe Mesoskopische Physik, Würzburg University, Germany

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Contact details

Dr Ana Helman
Science Officer
Ms Louise Kennedy
Administrator

Physical and Engineering Sciences Unit
European Science Foundation
1 quai Lezay-Marnésia
BP 90015
67080 Strasbourg cedex
France
Tel: +33 (0)3 88 76 71 62
Fax: +33 (0)3 88 37 05 32

Email: eurographene@esf.org
www.esf.org/eurographene

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Graphene

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