European Commission

THE SEVENTH FRAMEWORK PROGRAMME
The Seventh Framework Programme focuses on Community activities in the field of research, technological development and demonstration (RTD) for the period 2007 to 2013

GRAPHENE FLAGSHIP

The *Graphene-Based Revolutions in ICT And Beyond* (GRAPHENE Flagship) project is a CP-CSA supported by the European Commission Seventh Framework Programme Under contract 604391

COMPETITIVE CALL FOR CONSORTIUM EXTENSION

CALL CONTENT

Additional beneficiaries in the FET Flagships Project

604391 GRAPHENE

http://cordis.europa.eu/projects/rcn/109691_en.html
http://www.graphene-flagship.eu/

25 November 2013

Contents

Background

The GRAPHENE Flagship's consortium will be extended with another 20-30 beneficiaries through a competitive call issued in November 2013. **This competitive call is intended to further strengthen the engineering aspects of the flagship.**

The GRAPHENE Flagship consists of **11 scientific and technological (S&T) Work**

- Work package 1: Materials
- Work Package 2: Health and Enviroment
- Work Package 3: Fundamental science of graphene and 2D materials beyond graphene
- Work Package 4: High frequency electronics
- Work Package 5: Optoelectronics
- Work Package 6: Spintronics
- Work Package 7: Sensors
- Work Package 8: Flexible electronics
- Work Package 9: Energy
- Work Package 10: Nanocomposites
- Work Package 11: Production

The present competitive call addresses 12 research topics and one support topic (see page 6), **these call topics do not present a one to one correspondence with the GRAPHENE Flagship work programme** but should considered as elements cutting across some of the Work Packages interest.

More information about the GRAPHENE Flagship project: http://graphene-flagship.eu/

Funding

The expected average EC contribution is 708.000 € for each of the topics GF01-GF12 and the maximum funding for topic GF13 will be 250.000 €.

<u>For topics GF01-GF12</u>: The upper funding limit per proposal is 708.000 €. Up to two proposals will be selected for each topic.

<u>For Topic 13:</u> The upper funding limit per proposal is 250.000 €. Only one proposal is expected to be funded.

The total EC funding available through this call is 8,746,000 € from the FP7 budget. EC Contribution will have to be spent before the end of the Flagships' FP7 project, i.e. before March 31, 2016.

Evaluation

The GRAPHENE Flagship consortium will organise the evaluation of proposals received in the light of the standard FP7 evaluation criteria for Collaborative Projects with the assistance of at least two independent experts. These experts will be individuals from the relevant fields of science, industry and/or with experience in the field of innovation. They will hold the highest level of knowledge, and be internationally recognised authorities in their area.

Experts involved in the evaluation will sit in the Review Panels.

Each independent expert will record his/her individual opinion on each proposal he/she is asked to evaluate and give a score to each criterion (sing the form in form presented in annex 2). All experts evaluating a given proposal will then meet to agree on a consensus assessment for this proposal. A panel of experts will make a ranking based on this input. Using this ranking, the consortium will then select, in each of the 13 call topics, the proposal(s) with the highest overall score. Details on the evaluation process can be found the proposals handling and evaluation process document (http://www.graphenecall.esf.org/documents)

However, the GRAPHENE Flagship consortium is not obliged to select the highest scoring proposal when:

- A proposal raises objective concerns about commercial competition
- Significant erroneous claims impacting feasibility are made

Should this happen, approval from the European Commission services in charge of the GRAPHENE Flagship will be required to validate non-selection. In this case the choice may pass to the next-ranked proposal(s). It may happen that no other proposal score passes the minimum threshold in which case no selection will be made.

Also the GRAPHENE Flagship may conclude that even the highest scoring proposal is failing the minimum threshold, in which case it will make no selection.

In the event of no selection being made, the budget foreseen for the call-topic in question may be redistributed to other topics of the competitive call.

All proposers will receive from the GRAPHENE Flagship project the report of the consensus view of the experts who examined their proposal. The selected proposer(s) will be invited to accede to the project's grant agreement with the Commission.

(For more details about proposals handling and evaluation, see the document proposals handling and evaluation process – (http://www.graphenecall.esf.org/documents)

Rules of participation and eligibility

- Legal entities from EU Member States, FP7 Associated Country or created under EU law, International European Interest Organisations and Legal entities established in FP7 international cooperation partner countries (ICPC) are eligible to the call. International organisations and legal entities from third countries may receive funding only in very restrictive cases.

- **According to EC rules, groups from existing GRAPHENE Flagship beneficiaries (identified by their Participant Identification Code – PIC) are not eligible to apply through the competitive call.**
- Proposals can be submitted to the competitive call by single organisation or by consortia of organisations. For consortia there is no requirement of individual participants to be located in different EU member states (they can be national or Transnational).
- Proposals will be evaluated in the light of standard FP7 evaluation criteria for Collaborative Projects (see also annex 2 of the 'Guide for Applicants') and with the assistance of at least two independent experts per proposal appointed by the consortium.
- After approval from the European Commission services, new beneficiaries selected in the frame of the competitive call will:
  - enter the GRAPHENE Flagship consortium through an amendment to the Grant Agreement between the EU (represented by the European Commission) and the consortium.[1]
  - have to sign the Graphene Flagship Consortium Agreement (http://www.graphenecall.esf.org/documents).
- FP7 Rules for participation will apply, in particular for the Maximum Reimbursement rates of eligible costs:
  - Non profit public bodies; higher education establishments; research organisations - 75%
  - SME - 75%
  - Large companies and other organisations - 50%

(depending on the type of beneficiary and the type of activity to be carried out.)

A proposal will only be considered eligible if it meets all of the following conditions:

- it is submitted through the on-line submission system before the deadline, 5 February 2014, 16h00 (Brussels time);
- it is written in English
- it is submitted by an eligible participant (or a consortium of eligible participants); eligible participants are listed above.
- it is complete i.e. all elements forming the application (on-line and in the template to be used) have been provided (see also annex 1 of the 'Guide for Applicants')
- the content of the proposal relates to the call topic it addresses (see this Call Document and annex 5 of the 'Guide for Applicants')
- Requested EC contribution is within the funding limits specified in the call document

Timeline

- Call opens: 25 November 2013
- Call deadline: 5 February 2014
- Recommendations on new beneficiaries from the Scientific Panel to the European Commission: June 2014
- Accession of new beneficiaries: Autumn 2014

[1] Participation and funding of new beneficiaries is subject to normal FP7 rules concerning, amongst others, eligibility for funding and IPR sharing.

Call content

Proposals may be submitted under one of the following Topics:

Topic Nr	**Topic Title**	***Funding envelope per topic (k€)***	***Type of Activity***
GF01	Standardization	*708*	*RTD*
GF02	Chemical sensor, bio-sensors and bio-interfaces	*708*	*RTD*
GF03	Membrane technologies: from nanofluidics to nanoresonators	*708*	*RTD*
GF04	Catalysts for energy applications	*708*	*RTD*
GF05	Functionalized materials for composites and energy applications	*708*	*RTD*
GF06	Functional coatings and interfaces in high-performance, low-weight technological applications	*708*	*RTD*
GF07	Integration of graphene and related materials (GRMs) with semiconductor devices: a scalable back-end approach	*708*	*RTD*
GF08	New layered materials and heterostructures	*708*	*RTD*
GF09	Passive components for RF-applications	*708*	*RTD*
GF10	Integration with Si photonics	*708*	*RTD*
GF11	Prototypes based on graphene, related two-dimensional crystals, and hybrid systems	*708*	*RTD/Demo.*
GF12	Open topic *(Bottom Up)*	*708*	*RTD*
GF13	Updating the Science and technology roadmap for graphene, related two-dimensional crystals, and hybrid systems	*250*	*Other*

Note 1: type of activity

RTD activities: activities directly aimed at creating new knowledge, new technology, and products including scientific coordination.

Demonstration activities: activities designed to prove the viability of new technologies that offer a potential economic advantage, but which cannot be commercialised directly (e.g. testing of product like prototypes).

Other activities: any specific activities not covered by the above mentioned types of activity such as training, coordination, networking, **roadmapping** and dissemination (including publications). These activities should be specified later in the proposal.

Note 2: possible applicants are advised to inform themselves in the available literature on the multiplicity of existing 'Graphene and Related Materials' (GRM) first.

DETAILED DESCRIPTION OF THE INDIVIDUAL TOPICS

GF01 - Standardisation

Motivation

In order to drive products based on graphene and related materials (GRMs) to the market, standardized techniques for assessing and classifying GRMs are necessary. As GRMs usually feature multimodal properties (polydispersed sheet or grain size, density of defects, different oxidation grades, different mono- bi- few layers fractions, etc.), it is mandatory to define standard procedures to measure their porperties and to ensure consistent and repeatable quality of material in the market for different applications. Thus, any classification standard needs to be application driven, with parameters and properties tailored to the applications and measurement/assessment methods relevant for the end-use of the material. Such a classification system would allow grading the material. Well defined methods to measure the relevant properties of GRMs will, therefore, need to be standardized to avoid ambiguity for end users and customers.

Complementarities are envisaged with WP11(*Production*), WP1*(Materials),* WP3(*Fundamental Science*). Applicants must have a proven track record in the development of standards for industrially applied materials. All basic know-how in identification and characterisation of GRMs is present already in the Flagship. Proposal must demonstrate a feasible plan to create a standard, by combining the specific know-how of the applicants with that already present in the Flagship.

Objectives

- To achieve a reliable "toolbox" for GRM standardization. This may include the combination of structural characterization by local Raman, transmission-reflection measurements, microscopy (SEM, STM,AFM,EFM,TEM), Xray diffraction etc., as well as electronic transport measurements and magnetotransport, or any other technique that has been proven useful in assessing the chemical quality of GRMs (XPS, EELS, etc.), with the appropriate choice for the application targeted for.
- Standard procedures defining the measurement conditions, data treatment, interpretation tools
- Post-growth methods for quality control and industrial in-line monitoring.
- To create a connection with similar major European standardization initiatives, as well as with major Non-European efforts, such as those in Asia, USA, and Japan.

Impact

- Design of appropriate policies for workers and environment protection, as well as for the registration of GRM-based products.
- Standard procedures will enable the direct comparison between GRMs and devices produced by the different institutions.
- Speed up of optimization of growth processes with in-line standardized characterization for mass production.

GF02 - Chemical sensor, bio-sensors and bio-interfaces

Motivations

Graphene and related materials (GRMs) are highly sensitive to the interaction with molecules, making them ideal candidates for chemical sensing, allowing in principle single molecule detection. The efficiency of charge transfer is also very sensitive to the magnetic moment of the molecules, giving another degree of freedom for detection. Future advances include the development of new devices to interface sensors to biological systems, from single live cells to tissues. Graphene's low electrical noise and easy integration with flexible technology is promising for applications in neural prostheses. The combination of novel sensing technologies (electrical, electrochemical, optical) and biology could enable sub-cellular resolution of cell-surface potential dynamics, and lead to new devices.

This call topic targets the exploitation and development of novel technologies based on GRMs related to health applications, by exploring high-risk research directions with convergence of science and cutting-edge engineering.
Complementarities are envisaged with WP7(*Sensors*), WP2*(Health&Environment),* WP8(*Flexible Electronics*), WP1*(Materials).* Consortia are required to have at least one industrial partner.

Objectives

- Selective detection of single molecules, either in gas or aqueous phase. Complex molecules such as proteins, enzymes or peptides and even 2d-supramolecular layers can be considered as sensitive physisorbed layers.
- Cell-bionic systems. Technologies and strategies for bidirectional communication with living cells and biological tissue, aiming at cellular and subcellular resolution. These might be based on electrical, chemical, or optoelectrochemical communications, and should be able to report biological cell generated changes in the membrane surface potential, but also on chemical signals (neurotransmitters, ions, etc.) involved in cell communication
- Detection of electric field and chemical gradients at the membrane/cell surface. Time lapse images of surface potential changes or release of neurotransmitters.
- Development of multidirectional interfacing, e.g. therapeutic interfaces, such as neural prostheses, providing solutions to the challenges of mechanical mismatch between electronic devices and soft biological tissue.

Impact

- Market penetration of GRMs as sensors-inspiring components
- Innovative concepts in bionic systems
- Translation of basic discoveries into manufacturing products for clinical, environmental, or defence needs.

GF03 - Membrane technologies: from nanofluidics to nanoresonators

Motivation

Membranes are at the heart of many applications and industrial processes, such as desalination and water filtration, chemical analysis, energy harvesting, high-frequency electronics. Being an ultimate thin membrane with high mechanical strength, graphene has a unique potential in this field. Graphene membranes are extremely sensitive to small electrical signals, forces or masses due to their extremely low mass and large surface-to-volume ratio, and are ideal for nanoelectromechanical systems (NEMS). They have also been used as support for TEM imaging and as biosensors. Nano-mechanical resonators hold promise as components which can be used, e.g., in the front ends of transceivers. There is currently no other technology available that could bring tunability to a high-quality resonator and thus a filter, enabling adaptivity, will benefit current cellular multi-radio systems and future cognitive radio architectures. While graphene is expected to be impermeable to most fluids and gases, nanoholes with controlled size and distribution can be introduced, thereby allowing to reach (sub)nanometric scales in all dimensions. These can be used for single-molecule DNA translocation, paving the way to devices for genomic screening, in particular DNA sequencing. Graphene membranes are also promising for applications involving fluidic transport. Gradients of driving forces, hydrodynamic pressure/electric field/salt gradients, could induce a strong increase of transport, enabling in principle up to several orders of magnitude increase in efficiency. At the fundamental level, new models of fluid transport are now emerging from the confinement of liquids at the nanoscale, and membranes based on graphene and related materials (GRMs) could challenge the limits of continuum fluid transport.

Complementarity is envisaged with WP7(Sensors), WP2(Health and Environment), WP4(High-frequency electronics), WP1(Materials). Consortia should have a minimum of one industrial partner. Consortia targeting nanoresonators must be industry led.

Objectives

- Ultra-filtration, desalination, or new renewable energy production. In the context of desalination the GRM performance should be investigated in terms of flow permeability, salt rejection, etc., with the aim of surpassing the state of the art efficiency of reverse-osmosis.
- Methods to build large-scale membranes for nanofluidics.
- Energy harvesting technologies using membranes and fluids as vectors. Osmotic power, converting into electricity the free energy difference *e.g.* between sea water and fresh river water, could be explored. Demonstrators should target electric power conversion > 5 W/m^2.
- Nanoresonators. Vibration measurements from pA until few of femtoAmperes, in order to explore the yoctonewton detection range.
- High Q resonators for mobile and wireless applications

Impact

- Desalination and sustainable energy harvesting.
- Osmotic energy exploitation.
- Next generation mobile and wireless communications
- On-chip fast and precise gyroscopic sensors or nanoelectrical motors.
- Demonstration of low-cost GRM-based force microscope with high-resolution.

GF04 - Catalysts for energy applications

Motivation

One of the main challenges for green energy implementation is to ensure the continuous availability of energy or at least a lifetime of energy delivery consistent with the target application (i.e: electric vehicle, smart phone, etc.). Both issues generally require the combination of different energy storage/production solutions where the electrochemical devices appear as key components. These include batteries, fuels cells and supercapacitors. Some of these electrochemical components like metal-air batteries (Zn-, Li-air devices) or proton exchange membrane fuel cells (PEMFC) require large amounts of scarce and costly Pt catalyst, which strongly impacts their viability slowing down their introduction into market. Doped Few-Layer-Graphene (FLG) films with N-, B-, S-, P- or transition metal- hybridization (Fe, Co, etc) can potentially induce efficient oxygen reduction, while being less sensitive to catalyst poisoning (CO, Methanol, sulphur, etc.), thus promoting longer device lifetimes. In the same manner, biofuel cells (BFCs) can efficiently convert chemical reactions into electrical energy by means of enzymes or microbes grafted on carbon-based substrates. This paves the way to the development of novel Pt-free and cost-effective catalytic electrodes based on graphene and related materials (GRMs).

This call topic targets the development of Pt-free GRM-based catalyst electrodes and their integration into energy devices.
Complementarities are envisaged with WP9(*Energy Applications*), WP10(*Nanocomposites*), WP1*(Materials)*. Consortia should have at least one industrial partner

Objectives

- Investigate catalytic reaction pathways and catalyst ageing mechanisms, with an assessment of catalytic efficiency
- Demonstration of catalytic electrode integration into an electrochemical device with breadboard validation of the novel Pt-free electrode in a relevant environment.
- Development of GRM-based catalyst nano-materials that demonstrate their efficiency once integrated in energy devices. Different routes towards functionalization should be explored including orthogonal surface/border and double-sided decoration of GRM-based platforms to be achieved with new synthetic methods, including post-functionalization and supramolecular approaches.
- Targeted devices are proton exchange membrane fuel cells, enzyme-based biofuel cells and metal-air batteries.

Impact

- Enlarge and strengthen the impact of GRMs in energy applications.
- Provide industry with technological building blocks for manufacturing of sustainable and lower cost catalytic electrodes and related electrochemical components.
- Promote the integration of new industrial partners within the Flagship.
- Generate a new scientific and technological asset base on which SMEs can establish themselves as innovation players in areas with high potential for future commercial or societal impact.

GF05 - Functionalized materials for composites and energy applications

Motivation

Nanomaterials can offer a viable strategy to increase the energy conversion efficiency of current devices. E.g., in solar cells, the band gap engineering of semiconducting layered materials, organic semiconductors and nanocrystals can be exploited to optimize the light-to-electricity conversion efficiency (η). In Lithium-ion batteries, Li^+ hosting nanomaterials can enhance energy density, lifetime and cyclability of electrodes. The exploitation of wet processes is of foremost importance both for large scale production and for the realization of printed devices, the latter in high demand in the photovoltaics market. Semiconducting nanocrystal-based solar cells have seen a tremendous and rapid increase in light-to-electricity conversion efficiency. E.g., PbS nanocrystal-based solar cells can reach η=4.8%, while novel hybrid organic-inorganic solar cells using perovskite nanocrystals as sensitizer can have η>15%. The combination of perovskite compounds with graphene and related materials (GRMs) could be a step forward toward the replacement of electronically disordered, low-mobility TiO_2 nanoparticles in dye-sensitized solar cells. Similarly, batteries based on hybrid anode electrodes made of Si nanocrystals electronically interconnected with a hollow graphitized carbon nanofiber network have been recently developed. In this context, graphene, thanks to its electronic (*i.e.* high carrier mobility) and mechanical properties (*i.e.* flexibility) could provide a better network to both withstand large volume changes during the charge–discharge process and maintain efficient charge collection and transport.

This call topic targets the development of enabling technologies for the synthesis of hybrid GRM-based heterostructures usable as active materials. Projects should address both "reliable" and controllable heterostructures synthesis and their integration into energy devices. A test-bed validation of GRM-based composites in relevant environment is expected.
Complementarities are envisaged with WP9(*Energy Applications*), WP10(*Nanocomposites*), WP1*(Materials)*. Consortia should have at least one industrial partner.

Objectives

- Development of innovative GRMs that can improve the efficiency (e.g. light-to-electricity conversion efficiency, high specific capacity, cyclability, etc.) of energy conversion and storage devices.
- The targeted devices are highly efficient solar cells and high cyclability batteries.

Impact

- Enlarge and strengthen the impact of GRMs in energy applications.
- Develop technological building blocks for the manufacturing of efficient and low-cost solar cells, as well as higher cyclability batteries, demonstrating benefits for industrial exploitation.
- Promote the integration of new industrial partners within the Flagship.

GF06 - Functional coatings and interfaces in high-performance, low-weight technological applications

Motivation

Thanks to their monoatomic thickness and large aspect ratio, graphene and related materials (GRMs) can be ideal coatings to modify/improve the properties of an interface. Graphene's excellent mechanical, thermal, gas barrier and electrical properties have potential for high performance coatings with elevate stability, to prevent electrical or heath damage in harsh environments. E.g., in space applications temperature can quickly change from >400°C to <−140°C; out–gassing of volatile components, including desorption of water vapour, should be lower than 0.1 % mass; electromagnetic shielding form external sources or adjacent instruments is also a major issue. GRMs could provide electrical and thermal conductivity and yet be a cost-effective solution for high-added value applications (aeronautics, automotive, aerospace) were stability in extreme conditions, low-weight, low-permeability and high-performance are required. While protecting the substrate, these coatings can also give other functional properties, from basic ones (resistance to solvents, flammability reduction, UV radiation shielding, conductive-antistatic behaviour) to more complex functionalities, such as *in-situ* strain measurements in materials or devices subject to high mechanical or thermal stress.

This call topic targets functional coatings in interfaces (either buried or not) of technologically relevant composites. The main aim is to include GRM-based coatings in commercial, high performance composites, or high-power cables, either on the external surface or at the interface between different materials in the composite.
Complementarities are envisaged with WP10(*Nanocomposites*), WP1*(Materials)*. Consortia must be industry led.

Objectives

- Include GRM in the outer or inner interfaces of composites having a complex multi-scale architecture due to the presence of mesoscopic/microscopic additives. E.g., carbon and glass fibers or silica particles.
- Target functionalities such as: electrical conductivity, resistance to gas permeation, improved chemical properties, heat dissipation, high temperature stability.
- Benchmark the technological advantage of the obtained prototypes against composites based on 3-dimensional additives already commercial, such as carbon black, graphite powders, etc.
- Prototype material production must be on a relevant scale (i.e., larger than 200 grams or 100 cm^3 per batch).
- Metal-graphene-polymer composites to be used in the production of a new generation of high-power conductors, i.e. wires, cables and sheets exhibiting excellent electrical and thermal conductivity. Emphasis should be given on how the proposed approach is advantageous compared to present commercial technologies.

Impact

- Produce innovative functional composites featuring a complex, multi-scale architecture with GRMs at the interfaces between the different material components.
- Demonstrate the advantages of these GRM-based composites compared to 3-dimensional additives and powders already commercial.
- Demonstrate the feasibility and the industrial interest of the target application.

GF07 - Integration of graphene and related materials (GRMs) with semiconductor devices: a scalable back-end approach

Motivation

The integration of graphene and related materials (GRMs) with conventional semiconductor devices based on silicon, GaAs, GaN or InP will give rise to hybrid systems capable of exploiting the benefits of both sets of materials.

This call topic targets the back-end integration of GRMs on a semiconductor platform by developing an industrially scalable method for transfer and bonding of GRM films. The focus of the proposals should be on transfer and bonding of GRMs, and engineering the interface between GRM and semiconductor device. The potential of such hybrid systems, combining functionalities of the semiconductor materials and GRMs, should be demonstrated in a working integrated device

Complementarities are envisaged with WP4(High Frequency Electronics), WP5(Optoelectronics), WP7(Sensors), WP1(Materials), WP11(Production). Applicants need to demonstrate profound and proven expertise on industrial-scale semiconductor processing technologies. Consortia must have a minimum of one industrial partner.

Objectives

Proposals must address at least objective 1 and 2 for at least one GRM (i.e. graphene, MoS_2, etc.),

1. Develop a scalable route for wafer-scale integration of GRM films onto a semiconductor system. This should include the detachment of GRMs from the original carrier substrate, the handling and transfer of GRMs, substrate pre-treatment and GRM bonding to the semiconductor material. The final GRM film on the target substrate must show a carrier mobility larger than 4000 cm^2/Vs (the proposal should address directly this target and convincingly demonstrate it can be reached by the project end)
2. Design of GRM interaction with a semiconductor device in terms of electrical, mechanical, thermal and other contact properties, depending on the target application.
3. The quality of the integrated GRM layers should be assessed using state-of-the-art metrology techniques. This is preferably done through collaboration with existing Flagship partners, which should be indicated in the proposal
4. One possible application of such a hybrid system should be addressed

Impact

- Scalable approach for GRM integration on a semiconductor platform.
- Demonstrate the potential of GRM/ semiconductor hybrid system in an application within the field of High Frequency Electronics, Optoelectronics and/or Sensors.
- Strengthen the interaction of the Flagship with semiconductor industry.

GF08 - New layered materials and heterostructures

Motivation

Functional electronics and optoelectronics applications, based on materials with a spectral gap in the band structure, would require either modification of graphene, or its combination with other semiconductors in hybrid devices. A promising route towards making such devices is the use of graphene in conjunction with atomic layers of transition metal dichalcogenides (MX_2) and gallium chalcogenides (GaX), or by creating graphene heterostructures with thin films of III-V semiconductors. The feasibility of separating and even synthesizing atomically thin layers of MoS_2, $MoSe_2$, WSe_2, and WS_2 has been demonstrated, and this offers new perspectives for the development of electronics and optoelectronics based on atomically thin films.

The aim of this Call is to expand the materials base and characterisation capabilities of the Flagship, by targeting the investigation of atomically thin two-dimensional (2d) systems. This includes growth and studies of atomically thin 2d crystals beyond graphene; production of graphene heterostructures with semiconducting materials; investigation of their electronic and optical properties; development of applications of hybrid systems in functional device, and growth and preparation of new layered systems for spintronics .
Complementarity is envisaged with WP3*(fundamental science)*, WP1*(Materials)*, WP5(*Optoelectronics*), WP4*(High-Speed Electronics), WP6(Spintronics), WP9(Energy).*
The presence of one or more industrial partners in a Consortium is desirable, but not necessary.

Objectives

Proposals should target at least one of the following objectives:

- *Scalable growth of new types of atomically thin two-dimensional crystals beyond graphene and production of graphene heterostructures with semiconducting materials*. We expect proposals offering the expansion of fundamental studies onto a range of MX_2 and GaX crystals, graphene heterostructures with all of the above, and heterostructures of graphene with III-V semiconductors. The applicants will be expected to demonstrate their ability to produce such new systems and to perform their characterisation with changing structural and electronic properties and defects.
- *Characterisation of electronic and optical properties of new atomically thin 2d materials and implementation of hybrid graphene systems in functional devices.* We expect that the applicants will offer the access to characterisation infrastructure such as STM, advance optical characterisation (e.g., time-resolved or microcavity-enhanced optics, SNOM, ARPES), or THz characterisation technologies. In device applications, the focus is on tunnelling transistors, optoelectronics, or energy harvesting. The proposals should aim to demonstrate the proposed functionality in a prototype device.
- *New GRMs for spintronics devices*. Methods to induce locally spin-orbit interaction to couple electric and spin signals by adsorption of molecules or adatoms in order to generate spin signals by electric fields. Methods to fabricate systems which are (locally) ferromagnetic in order to make spin valve devices; or produce nanoribbons with edge-induced magnetic (ferro- or antiferromagnetic) properties.

Impacts

- Real world applications in functional electronics or high-end instrumentation development (e.g., detectors, sensors, etc).
- New device concepts that will change the currently available technologies and production methods in industrial sectors such as Electronics, Energy, Sensors etc.
- Stretching the fundamental limits of miniaturization in broadly used devices.

GF09 - Passive components for RF-applications

Motivation

While active RF-components based on graphene have been intensively investigated, passive components are less explored, and little work has been done in related layered materials. There is an ever-expanding interest in microwave materials for the design of antennas and RF devices in applications such as wireless communication, healthcare and energy harvesting. It is essential to quantify how they react against the electrical, magnetic or electromagnetic energy in terms of reflection, refraction, absorption, etc. However, there are fundamental limits in the design of microwave antennas and devices based on conventional materials, such as dielectrics: as antennas are made smaller, the bandwidth shrinks, the radiation resistance is smaller, and efficiency reduces. For users, this decreases bit-rate, limits range, and shortens battery life.

This call topic targets the development and testing of passive components, such as antennas, electrical interconnects, heat-spreading layers, filters and MEMS for different applications in the field of high-frequency electronics. Novel microwave antennas and devices including on/off switchable shielding, self-mixing antennas and optically transparent devices can also be considered.

Proposals within this call topic should focus on the design and experimental realisation of passive components based on graphene and related materials (GRMs) targeting applications in the field of high-frequency electronics (microwave to THz frequencies). The realisation of those devices needs to be supported by modelling, in order to achieve a description of all passive components to be integrated in industrial design tool.
Complementarity is envisaged with WP4(*High-frequency electronics*), WP1(*Materials*), WP7(*Sensors*), WP8(*flexible electronics*), WP5(*Optoelectronics*). Consortia should have a minimum of one industrial partner.

Objectives:

All three objectives must be addressed:

- Design and realization of passive RF-components based on GRMs. At least one component, either an antenna, an electrical interconnect or a filter, needs to be the focus of the proposal, while other passives, may be investigated additionally. The operation frequency of those components must fall in the frequency range from microwave to THz.
- Experimental verification of the component's performance using state-of-the-art characterization techniques and assessment towards the specific requirements for the target application.
- Applicants need to clearly indicate and discuss in the proposal the advantages of the envisioned passive component(s) with respect to conventional technologies.

Impact:

- Proof of principle demonstration of working prototype passive components based on GRMs.
- Validation of the expected potential of those components with respect to existing technologies.
- Provide the relevant parameters of those devices, which are needed for circuit design.

GF10 - Integration with Si photonics

Motivation
The combination of graphene's excellent electronic and optical properties with its large-scale manufacturability and compatibility with silicon technology make it a promising candidate for photonic integrated circuits. These systems are based on the convergence and co-integration of a large number of passive optical components (such as waveguides, (de-)multiplexers, and filters) with active optoelectronic devices (modulators, switches and photodetectors) on a single chip. Other layered materials also have potential, and are in need of further exploration

This call topic targets an approach to integrate graphene and related materials (GRMs) with Si waveguides and passive optical circuitry for next generation computing and communications systems. Specifically, a scalable approach should be demonstrated for future wafer-scale integration of existing CMOS-like Si manufacturing infrastructures. This should go beyond proof-of-principle (stand-alone) devices, and scalability of the technology should be demonstrated at pilot line level.
Complementarity is envisaged with WP5 (Optoelectronics), WP1 (Materials), WP4 (High-frequency electronics), WP7 (Sensors), WP8 (flexible electronics). Consortia should have proven wafer-scale (4" or larger) fabrication capabilities at industrial scale for CMOS and silicon photonics and interconnect circuitry. Proven experience with non-linear optical data processing is highly welcome.
.

Objectives
Objectives 1-3 are compulsory. Objective 4 is optional
1. Demonstrate the potential for wafer-scale (4” or larger) integration of GRMs with opto-electronic circuits based on a Si platform.
2. Demonstrate an optical interconnect (3 GBit/s for modulator + receiver), based on the integration of GRM-based modulators and detectors with Si photonic circuits. The device should cover all commercially important telecommunication wavelengths from the O-band (1260 to 1360 nm) to the U-band (1525 to 1675 nm).
3. The performance and energy-efficiency of the circuits should be optimized and assessed using state-of-the-art metrology techniques, and benchmarked with existing technologies.
4. Demonstrate the operation of nonlinear devices for all-optical data processing.

Impact
- A scalable approach for GRM integration with wafer-scale Si photonics platforms
- Demonstrate the potential of GRM-based optical interconnects and benchmarking with existing technologies.
- Strengthen the interaction of the Flagship with industry.
- Add to the Flagship a partner with proven CMOS-fab capabilities

GF11 - Prototypes based on graphene, related two-dimensional crystals, and hybrid systems

Motivation

The Flagship aims to develop various technologies and components up to the level where they can be utilised by industry. These include components for flexible electronics, printed electronics, biochemical sensors, various energy solutions, composites, optoelectronics, and high-frequency electronics, just to name a few. The Flagship will build the technology push for future commercial applications, but it is also actively seeking challenges from present day industry which could be solved by the technologies developed within the project. Applications such as wearable systems, smart textiles, flexible wearable displays, smart interactive windows or electronic paper could directly benefit from graphene and related materials (GRMs), demonstrating the progress of the Flagship Project. Such solutions should be verified by a prototype device, system or sub-system exploiting various components based on GRMs.

This call topic is expected to increase the technology readiness level of the Flagship, therefore a strong industrial involvement is essential. The Consortium must include a minimum of two companies and must be industry-lead. Additional academic partners are allowed, but only as support to the main industrial partners, and only if their competencies cannot be found in any of the existing Flagship academic partners. A set of specific target performance indicators must be indicated for each proposed devices. The proposed devices must show a competitive edge with respect to existing technology (e.g. in terms of transparency, flexibility, cost, etc.)
Complementarity is envisaged with WP8(*Flexible Electronics*), WP5(*Optoelectronics*), WP7(*Sensors*), WP9(*Energy Applications*), WP10(*Nanocomposites*).

Objectives

- Demonstrate a functional prototype device exploiting technologies and/or components based on GRMs.
- The technical performance should exceed the present state of the art; both of these should be defined in detail in the proposal. Other performance figures to be considered are potential product quality, estimated production-costs/cost-reduction and reduced environmental impact during the product life-cycle.
- Analyse the commercial feasibility of the proposed application/device/system at least in terms of manufacturability, supply-chain, environmental-stability and product life-cycle management.

Impact

- Strengthen the role of the Flagship within the European industry and increase awareness of opportunities given by GRMs.
- Novel commercial applications for technologies based on GRMs.
- Bring the technical challenges presently faced by industry to the core of the Flagship activities

GF12 - Open topic

Motivation

Technologies, and our economy in general, usually advance either by incremental steps (e.g. scaling the size and number of transistors on a chip) or by quantum leaps (transition from vacuum tubes to semiconductor technologies). Disruptive technologies behind such revolutions are usually characterised by universal, versatile applications, which change many aspects of our life simultaneously, penetrating every corner of our existence. To become disruptive, a new technology needs to offer not incremental, but dramatic, orders of magnitude improvements. Moreover, the more universal the technology, the better chances it has for broad base success. This can be summarized by the "Lemma of New Technology", proposed by Herbert Kroemer: "The principal applications of any sufficiently new and innovative technology always have been – and will continue to be – applications created by that technology". Graphene is the first of a new class of materials with huge potential for applications, including tens of other two-dimensional crystals, hetero-structures based on these crystals, and their hybrids with metallic and semiconducting quantum dots and other nanomaterials. A key step to advance the commercial viability of graphene is to harness the emerging capability in graphene technology – including novel applications and production technologies.

At present, the realisation of an electronic device requires the assembly of a variety of components obtained by many technologies. Graphene, by including different properties within the same material, may offer the opportunity to build a comprehensive technological platform for the realisation of almost any device component, including transistors, batteries, optoelectronic components, photovoltaic cells, (photo)detectors, ultrafast lasers, bio- and physico-chemical sensors, etc. An even wider set of properties can be targeted by considering other two dimensional crystals, layered materials, and hybrid structures resulting from their juxtaposition or integration with other materials, including quantum dots, nanowires, nanotubes, etc.

The field of graphene and related materials (GRM) is progressing at a rapid rate, making it difficult to reliably predict new important technological advances. **This open topic** call topic **targets new emerging phenomena or challenges that are not covered by the 12 other topics or by the existing Flagship WPs**. Topics of interest may include (but are not limited to) advanced nanofabrication of graphene-based devices and all-graphene spintronics; multifunctional composites for high-power cables; computational modelling of devices and systems based on GRMs; active THz components; Immunogenomics and proteomics studies of GRMs.

Complementarities with one or several of the 11 scientific and technological WP is a requirement. Proposals must demonstrate the importance of their topic in terms of scientific advances and societal impacts and present a feasible plan to reach their goals during the project period. Industrial participation is strongly encouraged.

Objectives

- To advance the field of the GRM science and technology in directions not covered by other parts of the flagship nor by any of the other topics of this call for proposals.

Impact

- Increase the engineering aspects of the Flagship and promote the utilization of GRMs
- Identify new killer applications created by the novel GRM technology

GF13 - Updating the Science and technology roadmap for graphene, related two-dimensional crystals, and hybrid systems

Motivation

A science and technology roadmap (STR) for graphene, related two-dimensional (2d) crystals, and hybrids, was developed in the Pilot Phase of the GRAPHENE Flagship. A synthesis of this document is available in the call document page (http://www.graphenecall.esf.org/documents). The STR targets an evolution in technology, with impacts and benefits reaching most areas of society. It outlines the main targets and research areas as best understood at the start of this project.

The primary objective of the STM is to guide the community towards the development of products based on graphene, 2d crystals and hybrid systems. For simplicity we will refer to this new material platform as graphene and related materials and use the acronym GRM. These materials have a combination of properties that could make them key enablers in many application fields, generating new products that cannot be obtained with current technologies or materials. The creation of new disruptive technologies based on GRMs is conditional to reaching a variety of objectives and overcoming several challenges throughout the value chain, ranging from materials to components and systems.

The STR outlines the principal routes to develop the GRM knowledge base and the means of production and development of new devices, with the final aim to integrate GRMs into systems.
It is essential to keep the STR updated, monitoring the state of the art of the IP landscape, industrial trends, achievements and setbacks over the Flagship period.

The work is expected to be done in cooperation with the main institutions and authors who contributed to the existing STR. The applicants must have a proven track record in development and production of high-impact status-reports and future-outlooks for novel and emerging technologies.

Objectives

- Develop a methodology for updating the existing STR every 2 years. This will require interaction with key stakeholders in EU and worldwide, IP landscape research, data collection and analysis.
- Implementing the first major STR update by the end of the ramp-up phase of the Flagship

Impacts

- The STR is the most important document of the Flagship DOW. The updated STR will impact future expansion and funding of the Flagship, as well as direct industrial development of GRMs in EU and worldwide