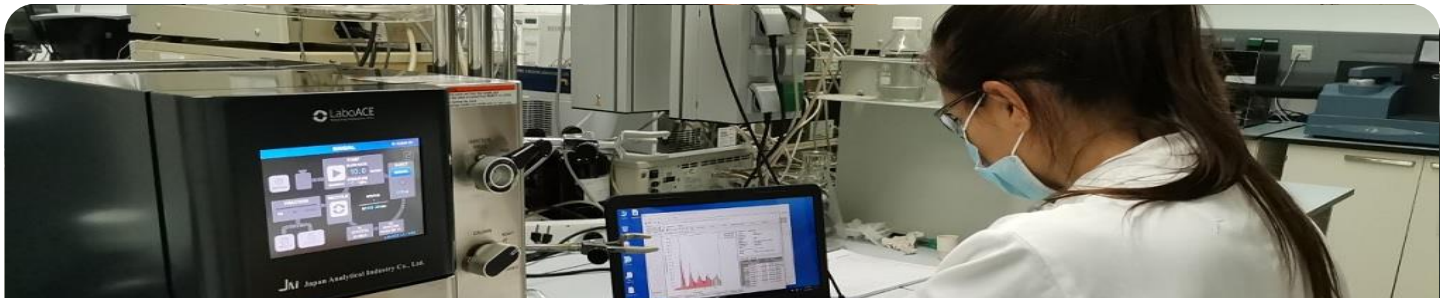
Spin Research IN Graphene first Newsletter



SPRING NEWSLETTER #1

Welcome to the first issue of the SPRING newsletter!

SPRING stands for "SPin Research In Graphene". It is an EU-funded interdisciplinary project covering scientific fields such as two - dimensional nanostructures, graphene, spintronic, natural sciences, and data processing amongst others. The consortium consists of six international partners, which collaborate with the goal of testing the potential of graphene nanostructures as building block for spintronic devices.

This newsletter invites you to get to know the nature of the project, the involved consortium partners, our vision, the objectives we aim to accomplish, the results we have achieved up to date, activities and events undertaken, as well as the challenge to perform science in pandemic times.

Thank you for your interest in our successful research story!

The SPRING consortium

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THE SPRING PROJECT

The SPRING project combines recent scientific breakthroughs from the six European consortium members to fabricate custom-crafted magnetic graphene nanostructures and test their potential as basic elements in quantum spintronic devices. The targeted long-term vision is the development of an all-graphene – environmentally friendly – platform where we aim to use spins for transporting, storing, and processing information.

The EU-funded H2020 project SPRING grants us to develop new graphene-based magnetic components that can contribute to the creation of faster and environmentally friendly electronic devices. The coordination institute of our international research project is CIC nanoGUNE (ES) in partnership with IBM (CH), University of Santiago de Compostela (ES), Technical University of Delft (NL) and University of Oxford (UK), and Donostia International Physics Center (ES).

AREAS OF RESEARCH

An added value of SPRING is the multidisciplinary character of the collaborative research approach, including the following thematic scientific areas:

Physical Chemistry	Condensed Matter Physics
Quantum Physics	Physical Engineering
Organic Synthesis	Quantum Technology

Furthermore, partners in complementary sectors provide a rich and ideal environment for accessing to all stages of scientific development.

SPIN RESEARCH IN GRAPHENE

Spin is a fundamental property of some subatomic particles. Although it has not classical equivalent to describe it, spin can be understood in a loose way as the rotation of a fundamental particle of matter around itself- Every electron in any material carries both a charge and a spin, the latter playing a key role in magnetism. Therefore, spin is the ideal property of matter to expand the performance of current charge based nanoelectronics into a class of faster and more power-efficient components, being this the basis for the emerging technology called *quantum spintronics*. The SPRING project will investigate the fundamental laws for creating and detecting spins in graphene; this is to read and write spins and using them to transmit information.

While magnetism is usually associated with spins of electrons in d or f states, π electrons in graphene can also give rise to magnetism, the so-called π-paramagnetism. This form of unconventional magnetism emerges spontaneously as radical states in open-shell graphene structures. Graphene π-paramagnetism is more delocalized, mobile, and isotropic than spins in d-orbitals of transition metals, all very attractive properties for spintronics. Importantly, it can be electrically addressable. SPRING aims to develop concepts, tools, and methods for producing open-shell graphene nanostructures with a designed shape for emergent π-magnetization. Our aim is to demonstrate that these materials can become potential platforms for quantum spintronic devices.

OUR VISION & OBJECTIVES

The aspiration that is driving us through our project is the creation of a novel generation of graphene nano systems behaving as paramagnetic materials and the verification and validation of their potential in future technology. Furthermore, SPRING envisions to explore control of dynamical nuclear spin polarization in graphene-based nanostructures by electrical currents in three-terminal devices and lay the groundwork for a long-lived nuclear-spin classical or quantum memory.

To accomplish this goal, SPRING is structured along three main research lines:

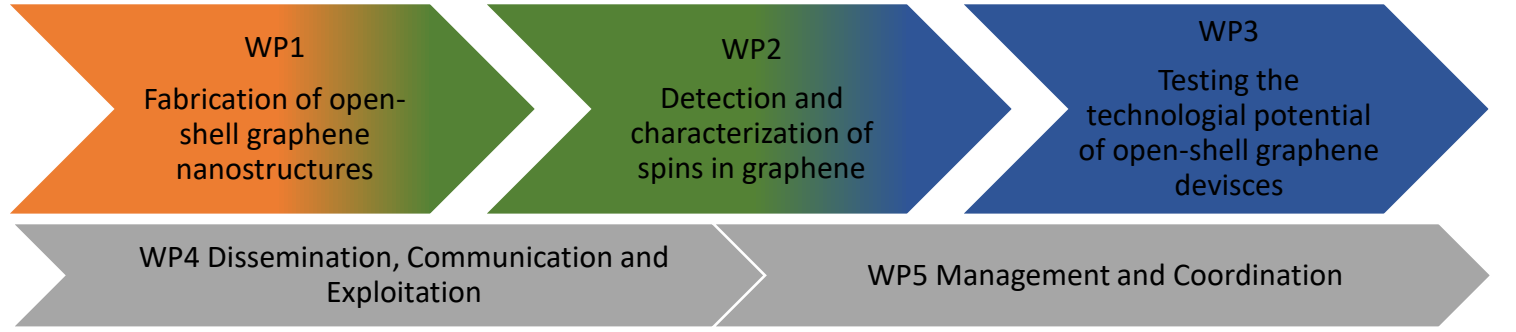
- On-surface synthesis strategies will be utilized to create ***atomically precise open-shell graphene* nanostructures**, including frustrated magnetic states, spin-polarized bands, and spin chains.
- SPRING will demonstrate the emergence of π-magnetization and unveil the time and energy scales of ***spins in the open-shell structures*** through a combination of scanning probe and electron spin resonance spectroscopies and develop novel predictive models of their quantum functionality.
- The ***potential of graphene open-shell platforms*** as a novel paradigm in spin-based logic devices will be tested by incorporating them into model devices and electrically addressing and manipulating spins.

RESEARCH METHODOLOGY

SPRING is organized in three scientific WPs (work packages) addressing the research objectives of SPRING, and two WPs for dissemination, communication, exploitation & management, and coordination.

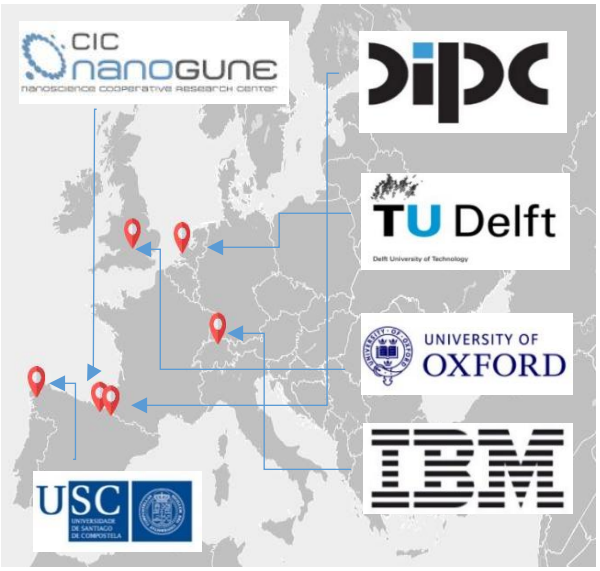
- ***WP1*** will use in-solution organic synthesis, exploratory Density Functional Theory, and mean-field Hubbard simulations, on surface synthesis and high-resolution probe microscopy (AFM & STM).
- ***WP2*** uses scanning tunneling spectroscopy (STS) measurements of spin-dependent-electrical fingerprints, Atomic Force Spectroscopy, DC magnetization, Pulsed-Electron Spin Resonance (ESR) and Electron-Nuclear Double Resonance (ENDOR), DFT and model simulations.
- ***WP3*** will use transport measurements in three-therminal device (3TD) geometries and in STM, charge manipulation with AFM, DFT and mean-field Hubbard simulations, phenomenological theory, pulsed ESR and ESR based nuclear spin spectroscopy experiments (ESEEM, HYSCORE, and ENDOR).
- ***WP4*** will be in charge for the dissemination, communication and exploitation of activities and research results.
- ***WP5*** will deal with the scientific and administrative management of SPRING.

Overview of the different work packages and their tasks



THE CONSORTIUM

The SPRING project consists of six international partners from European countries, combining different fields of scientific expertise.



THE PARTNERS

NGU – CIC nanoGUNE

CIC nanoGUNE is a research institute in San Sebastian, with the mission of carrying research in nanoscience and nanotechnology, for increasing business competitiveness and economic development in the Basque Country. In 2017, NGU has inherited the recognition as "María de Maeztu" Excellence Unit and member of the Basque Research and Technology Alliance (BRTA).

TECHNICAL UNIVERSITY DELFT

TUDelft engineering university hosts a challenging and interdisciplinary research environment in their department of Quantum Nanoscience. Endowed by the prestigious Kavli Foundation, their focus lies on investigating physical processes on nanoscale.

USC - UNIVERSIDAD DE SANTIAGO DE COMPOSTELA

USC is a public university established in 1495 and recognized as International Campus of Excellence. At USC, CiQUS develops transdisciplinary strategies to undertake major challenges in Molecular Sciences.

IBM RESEARCH GMBH

IBM is a globally integrated technology and consulting company, world-renowned for its outstanding scientific achievements. For their invention of the scanning tunneling microscope (STM) and the discovery of high-temperature superconductivity, they received Nobel Prizes.

UOXF – UNIVERSITY OF OXFORD

The University of Oxford and its physic department play a leading role nationally and internationally. They work on major facilities worldwide; develop advanced experimental techniques and sophisticated theoretical methods to investigate nature at every scale and every temperature.

DIPC – DONOSTIA INTERNATIONAL PHYSICS CENTER

The research center DIPC in Donostia San Sebastian has its focus on performing and catalyzing cutting-edge research in physics and related disciplines. The "Basque Excellence Research Center" (BERC) also recently received recognition as a "Severo Ochoa" Excellence Center in 2019.

THE TEAMS

Measuring, detecting and manipulating materials with atomic precision is one of the main research activities of ***Jose Ignacio Pascual***, coordinator of the SPRING project. He is Ikerbasque Research Professor and the leader of the Nanoimaging group at CIC nanoGUNE - Spain since 2012. His research team includes ***Martina Corso***, PhD. in Surface Sciences. ***Jingcheng Li***, PhD. in Physical Sciences. ***Jeremy Gérard Hieulle***, postdoctoral researcher and ***Alessio Vegliante***, PhD student.

Developing of on-surface synthesis by atom manipulation is just one of the main research aspects and expertise of the team lead by ***Leo Gross***, Research Staff Scientist at IBM. Together with the post-doctoral fellow, ***Florian Albrecht***, PhD. students ***Katharina Kaiser*** and ***Shadi Fatayer***, they work on cutting edge research results in quantum mechanics. As a successful industrial partner in the projects target market, IBM has an exceptional wide outreach capacity that we exploit to maximize project communication and exploitation activities.

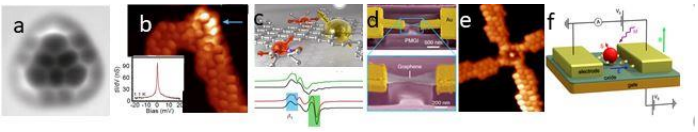
Developing innovative fabrication and measurement techniques, through electrical characterization is one of the research areas that ***Herre van der Zant*** pursues at TU Delft. Quantification of spin-spin interactions and general studies of electronic transport adds to the professional profile by his postdoctoral Researcher ***Maria El Abbassi*** and PhD student ***Thomas Baum***.

Arzhang Ardavan is Professor in Physics and a Tutorial Fellow in Physics at Magdalen College, UOXF. The expertise of him and his postdoctoral Research Assistant, ***Junjie Liu***, lies in continuous-wave and pulsed electron spin resonance experiments in spin-bearing molecular complexes and pulsed electron spin resonance. Their strong interest in condensed matter physic and strongly correlated electron systems and quantum magnetism adds high value to the SPRING project.

Diego Peña works in organic synthesis at CiQUS (USC) in collaboration with his research group Juan de la Cierva Researcher ***Fátima García***, Full Professor ***Dolores Pérez Meiràs***, postdoctoral Researcher ***Silvia Castro*** and PhD student ***Saleta Fernández***. Their role in the SPRING project is the solution synthesis of organic precursors and highly reactive molecules.

Thomas Frederiksen, Ikerbasque Research Professor at DIPC, leads the research team in SPRING. The group works on quantum transport theory and electronic structure methods. They use supercomputing facilities to perform large-scale simulations based on density functional theory and nonequilibrium Green's functions and develop new methodology and code implementations. The team includes Ikerbasque Research Associate ***Aran-Garcia Lekue***, Ikerbasque Research Professor ***Geza Giedke***, CSIC Research Professor ***Daniel Sanchez Portal***, and postdoctoral Researcher ***Carlos García Fernández***.

RESEARCH RESULTS

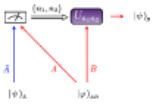


Previous breakthroughs pioneered by SPRING members as scientific basis of graphene quantum spintronics: a) OSS synthesis of the open-shell triangulene; b) Spin localized in graphene junctions; c) Magnetic state in graphene and manipulation by pulsed ESR; d) Quantum interference in graphene junctions; e) Spin survival in a porphyrin contacted by graphene nanoribbons; f) Spin radicals and coupling in transport experiments

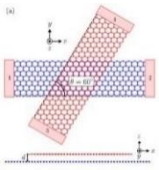
In this section, you will find a selection of publications by SPRING consortium partners published in the first year.

QUANTUM TRANSPORT

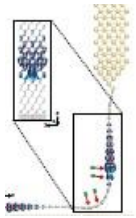
Different modes of encoding and transporting information have been predicted in our consortium.



Teleporting quantum information encoded in fermionic modes
Tiago Debarba et al. Phys. Rev. A 101, 052326 (2020)



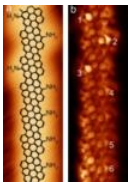
Crossed graphene nanoribbons as beam splitters and mirrors for electron quantum optics
Sofia Sanz et al. Phys. Rev. B 102, 035436 (2020)



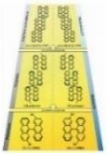
Magnetism of topological boundary states induced by boron substitution in graphene nanoribbons
Niklas Friedrich et al. Phys. Rev. Lett. 125, 146801 (2020)

FABRICATION OF NANOGRAPHENES

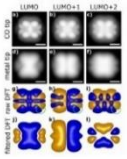
Several results contributed to the fabrication of graphene flakes and ribbons with atomic precision using a combination of solution synthesis of organic precursors and chemical reactions over metal substrates.



Band Depopulation of Graphene Nanoribbons Induced by Chemical Gating with Amino Groups
Jingcheng Li et al. ACS Nano 14,1895 (2020)



Transferring axial molecular chirality through a sequence of on-surface reactions
N. Merino-Díez et al. Chem. Sci, 11, 5441 (2020)

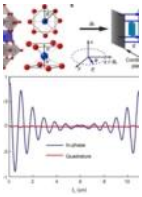


Intramolecular coupling of terminal alkynes by atom manipulation
Florian Albrecht et al. Angew. Chemie. Int. Ed. 59, 1 – 6 (2020)

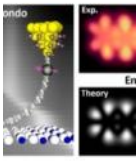
DETECTION OF SPIN IN GRAPHENE

Spectroscopic fingerprints of spins were detected demonstrating novel properties of pi-paramagnetism.

Uncovering the triplet ground state of triangular graphene nanoflakes engineered with atomic precision on a metal surface
Jingcheng Li et al. Phys. Rev. Lett. 124, 177201 (2020)



Quantum coherent spin-electric control in molecular nanomagnets
Junjie Liu et al. arXiv:2005.01029v1 (2020)



Probing the Magnetism of Topological End States in 5-Armchair Graphene Nanoribbons
James Lawrence et al. ACS Nano 14, 4499 (2020)

EXTERNAL ADVISORY BOARD

The External Advisory Board (EAB) consists of high-level researchers in the field, who will contribute to the scientific progress of the project.

We are happy to welcome their presence in our consortium and look forward to fruitful collaborations:

Prof. em. Dr. Silvio Decurtins is Professor in Chemistry at the University of Bern, Switzerland. The fundamental objective of his work is to design, synthesize and characterize new materials for which different physical properties such as magnetism, electrical conductivity, photophysical properties, etc. are combined in a synergistic way.

"I judge that the SPRING consortium is strongly positioned and placed with experts in order to achieve set goals."

Prof. Antti-Pekka Jauho Prof. Antti-Pekka Jauho works at the Physics Department of DTU and leads a Center of Excellence for nanostructured graphene (CNG). The key idea is to investigate both theoretically and experimentally the new functionalities that nanostructuring may introduce to graphene or other two-dimensional materials.

Dr. Clemens Winkelmann is Associate Professor at the Néels Institute in Greneble since 2008. His research focuses on the experimental study at very low temperatures of quantum effects in nanoelectronic systems, such as superconducting devices and graphene.

COVID 19 CHALLENGES

The year 2020 turns out to be outstanding when it comes to facing challenges. As the COVID 19 pandemic hit early this year, research institutions around the world started to slow down. Despite different guidance instructions in European countries during this time, most workplaces recommended to work from home as much as possible. Avoiding close contact to colleagues and project partners was and still is recommended. As a result, scientific research and equipment heavy lab work has been and still is affected since the beginning of March 2020.

Reports from the SPRING consortium partners about the COVID 19 impact differ from each other due to diverge research disciplines and work routines. Some institutions experienced lab close downs until May 2020 and had to adapt their experimental activities to the new restrictions. Reducing the size of work groups in the lab to ensure social distancing measures still is a hurdle. Those groups producing theory and computation were less affected and adapted quickly to the new workflows from home.

However, the consortium partners managed to produce exciting research results which led to outstanding journal publications in the first year. The necessary reduction of faculty members, students and staff members in the research institutes effected the work situation, too. But operating under new restrictions also offered new possibilities:

Let's go online! Conferences, talks, seminars, meetings, workshops, presentations, interviews and even hiring of new research staff were done virtual.

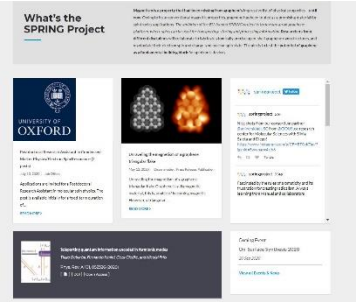
NEWS & EVENTS

The SPRING projects aims to reach out to the society as well as stakeholders and potential project partners alike. Therefore, to promote our actions and their results to various audiences, we make use of strategically planned communication and dissemination. To name activities and events with most impact of the first project year:

Radio Interview with Diego Peña (USC): O grafeno, futuro da computación cuántica? Radio Galega local radio station: regarding our joint PRL press release "Unraveling the-magnetism of a graphene triangular flake", 21.05.2020

Article about the SPRING project: "Grafeno, el futuro escondido en la punta del lápiz"Newspaper article, GARA science journal, 29.05.2020

Public event: "Die Lange Nacht der Unternehmen" with Katharina Kaiser (IBM), (long light of corporations). Presentation: 'Spitzen-Forschung - Molekuele unter der Lupe', Rueschlikon, 7.11.2019



Furthermore, we actively engage with the open public and scientists through our ***webpage*** www.springfetopen.eu and ***social media*** accounts Twitter and Instagram.

THE KICK-OFF MEETING

The SPRING project has celebrated its kickoff meeting on the 7th and 8th of November 2019 in Donostia / San Sebastián (Spain). The meeting marked the starting point of this project.

UPCOMING EVENT

When: 30.09.2021 – 05.10.2021
Where: Sant Feliu de Guíxols, Girona - Spain
Organizer: DIPC – Donostia International Physics Center

Bridging the fields of chemistry, physics, and materials science, the upcoming fourth edition of the "On-Surface Synthesis" international 5-day workshop is about merging expert researchers with different backgrounds.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 863098.