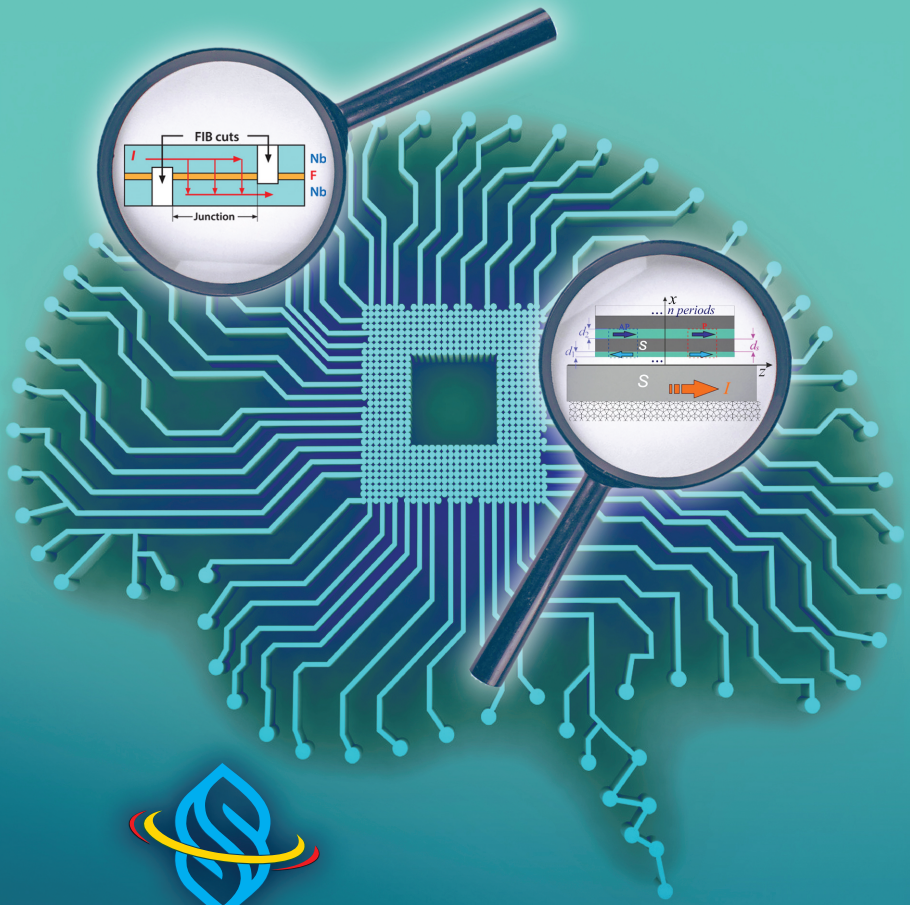
Anatolie Sidorenko

EU Project "SPINTECH" the Key to Boosting of Excellence of D. GHITU IEEN in Spintronics



SPINTECH

Anatolie Sidorenko

Project “SPINTECH” – the key to boosting of excellence of D. GHITU IEEN in spintronics

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Content

SPINTECH
(Grant Agreement number 810144)

"Boosting the scientific excellence and innovation capacity in spintronics of the D. GHITU Institute of Electronic Engineering and Nanotechnologies of the Academy of Science of Moldova"
Funding Scheme: Research and Innovation Action
Call: H2020-WIDESPREAD-2016-2017
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The main goal of the SPINTECH project, as it is written in the Grant Agreement #810844, aims at boosting the scientific excellence and innovation capacity in spintronics of the D. Ghiţu Institute of Electronic Engineering and Nanotechnologies (IEEN) through collaboration and staff exchange with two highly experienced European partners: the University of Stockholm in Sweden and the University of Twente in the Netherlands.
This two partners of the D.GHITU Institute of Electronic Engineering and Nanotechnologies of Moldova, University of Twente and University of Stockholm, have a long history of increasing excellence.

Stockholm University (SU)
Founded in 1878, **Stockholm University** is one of the largest universities in Scandinavia. The institution is regarded as one of the world's top 100 universities by the Academic Ranking of World Universities (ARWU)[1] - whereas, in the Times Higher Education World University Rankings (THE)[2] and in the QS World University Rankings[3], the SU is among the 200 universities in the world. SU has more than 70,000 students, 1,800 doctoral students and 5,000 staff. The Condensed Matter and Quantum Optics Division of the Department of Physics has a strong expertise in research in the field of hybrid superconductor/ferromagnet devices for spintronic applications and development of ultrasensitive nanocalorimetry methods. In particular, the **Experimental Condensed Matter Physics Group,** started in February 2005, is focused on the study of mesoscopic phenomena in condensed matter physics.
In their research, the Experimental Condensed Matter Physics Group is employing mesoscopic superconducting elements and nanotechnology both for fundamental

[1] Academic Ranking of World Universities (ARWU)
[2] Times Higher Education World University Rankings (THE)
[3] QS World University Rankings

research, which may challenge and expand principles of condensed matter physics, and for applied research aiming at development of novel phase-coherent components for future nanoelectronics and spintronics. The research areas span from superconductivity, with emphasis on high temperature superconductors (HTSC), low temperature physics, quantum electronics and spintronics, and nanotechnology. Current research topics are: intrinsic tunnelling spectroscopy of HTSC, THz applications of superconducting tunnel junctions, analysis of non-equilibrium effects in natural atomic superlattices, study of hybrid superconductor/ferromagnet devices for spintronic applications and ultrasensitive nanocalorimetric studies of electronic properties of new superconductors.

University of Twente (UTWENTE)

University of Twente is one of the best universities of the Netherlands and is an entrepreneurial university. Its research is highly regarded at both the national and international levels, and is accommodated within very active research institutes focused on nanotechnology, information technology, biomedical technology and technical medicine, governance, behavioral sciences and geo-information science and earth observation. The research institutes combine scientific excellence with a sharp eye for knowledge valorization and social applications. They are highly successful in generating spin-off businesses. The University has 3,300 scientists and other professionals working together on cutting-edge research, innovations with real-world relevance and inspiring education for more than 9,000 students. **MESA+** is one of the world's largest nanotechnology research institutes. It is also the largest research institute in this field in the Netherlands, having a total of 525 researchers. **The Interfaces and Correlated Electron systems group (ICE)**, which will be involved into the project, is focuses on materials and interfaces with unconventional electronic properties, especially related to interactions between the mobile charge carriers. Their research aims at bridging fundamental studies with application-oriented 'proof-of-principle' device developments. Most of the experimental research concentrates around thin film samples, which are fabricated in house with advanced thin film deposition and structuring techniques. The group is comprised of almost 40 people, including 5 Prof. Drs, 10 PhD and 8 MSc students, as well as 6 post docs.

Moreover, UTWENTE has a strong track-record of spin-off companies based on the results of research activities conducted at the University. In particular, the UTWENTE's Institute for Nanotechnology MESA+ is the birthplace of more than 50 spin-offs. The institute regularly organises Early Business Development workshops aimed at encouraging researchers to commercialise the obtained results.

Coordinator of the project – **D. GHITU Institute of Electronic Ingineering and Nanotehnologies of Moldova (D. GHITU IE)**

The **D. GHITU Institute of Electronic Ingineering and Nanotehnologies of Moldova** is a leading scientific centre of the country, developing new research trends in material science. In 2016 it was accredited by the Highest Accreditation Commission of Moldova

(CNAA) as an “excellence research institute”. The organisational framework of D. GHITU IE consists of 5 departments and 162 staff (70 engineers and 73 researchers, of which 39 hold a Doctor of Sciences degree). D. GHITU IE’s research is focused on investigation of physical processes and electronic transport in meso- and nanoscale structures and their implementation for engineering of electronic devices and functional systems. The areas of D. GHITU IE’s applied research include:

- Novel technologies of materials and solid state structures fabrication for engineering of electronic devices and functional systems;
- Development of materials, structures and nanotechnologies, engineering of based on them functional elements for smart devices, systems and electronic products;
- Electronic structures, sensors and devices for investigation of biophysical processes under impact of non-ionizing non-thermal radiation (of GHz and THz waves) and high-fidelity sensors for temperature and pressure measurement in industrial processes.

The project was carried out by the **Cryogenic laboratory of D. GHITU IE**, whose main activities are the following:

- Development of different vacuum technologies for fabrication of superconducting compounds, MgB2 films and superconductor/ferromagnet nanostructures, using MBE, MOCVD, DC and RF magnetron sputtering.
- Experimental research of critical temperature, critical magnetic fields transport and magnetic properties of superconducting layered nanostructures.
- Development of electronic devices for microelectronics and spintronics, sensors designed for environment monitoring: air humidity, temperature, pressure, gases concentration.

Simultaneously with working together with the project SPINTECH partners, University of TWENTE and Stockholm University, D.GHITU IE has a long-term collaboration also with several other European research centers: Max-Planck Institute Stuttgart (Germany), Institute of Nanotechnology KIT Karlsruhe (Germany), University of Augsburg (Germany), Loughborough University (UK), University of Amien (France), University of Bordeaux (France), M.Lomonosov Moscow State University (Russia), Kazan State University (Tatarstan) – that fruitful collaboration was a good support for the project implementation.

To achieve the aims of the project during the 3,5 years of its realization, the partners implemented a research and innovation strategy with the following 5 objectives:

Objective 1: Strengthen IEEN’s research excellence in spintronics.

• **Objective 2**: Enhance the research and innovation capacity of IEEN and the Twinning partners.

• **Objective 3**: Raise the research profile of IEEN and the Twinning Partners.

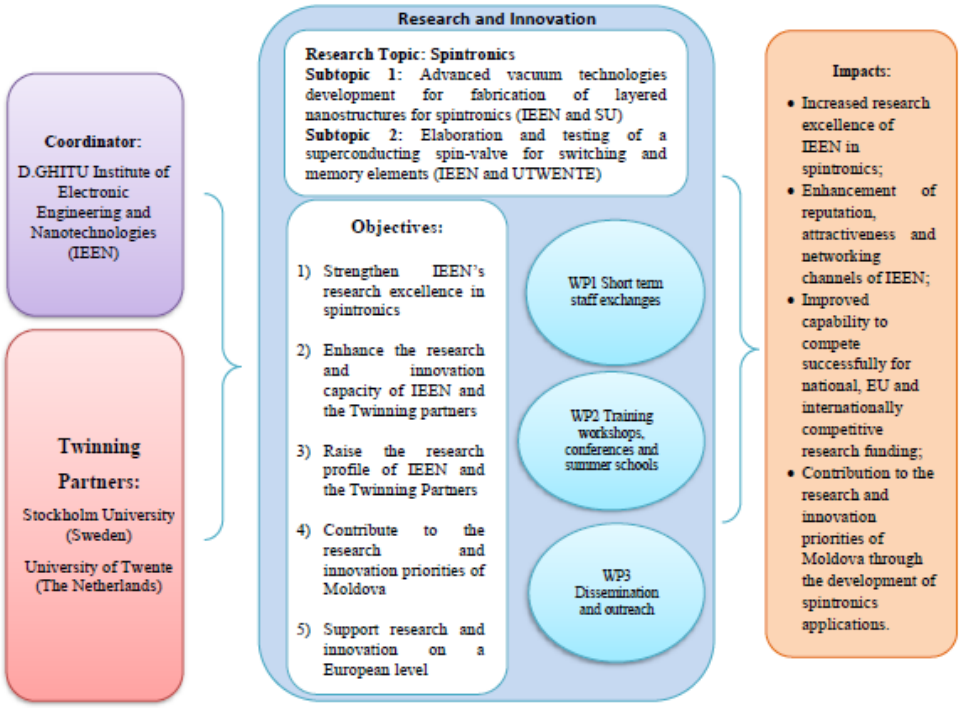
• **Objective 4**: Contribute to the research and innovation priorities of Moldova.

• **Objective 5**: Support research and innovation on a European level.

In order to achieve these objectives, the consortium partners put into practice a comprehensive set of **measures** via the project’s work packages, which included:

1. Short term staff exchanges (WP1);
2. Training workshops, 2 conferences, winter and summer schools (WP2);
3. Dissemination and outreach activities (WP3).

The overall concept of the SPINTECH project and its impacts are captured in the following figure:



During the project implementation collaborators of all three organizations (IEEN D.GHITU, UTWENTE and SU) participated in staff-exchange visits, training workshops, winter- and sommer- schools, conferences and outreach activities:
From D.Ghitu Institute of Electronic Engineering and Nanotechnologies, Moldova, **IEEN "D.GHITU" – 32 persons:**
Scientific collaborators: Prof. Anatolie Sidorenko, Prof. Feodor Muntaen, Dr. Alexander Penin, Dr. Elena Condrea, Dr. Roman Morari, Dr. Andrei Prepelita, Dr. Lilia Bujor, Dr. Evgheni Antropov, Dr. Gheorghe Para, Dr. Victor Cojocaru, Dr. Dmitrii Dvornicov, Dr. Efim Zasavitchi, Dr. Alexander Belenciuc, Dr. Oleg Sapoval, Dr. Vladimir Fedorov, Dr. Oleg Bujor, **Engineers:** Daniil Caraghenov, Igor Belotserkovschi, Tatiana Gutul, Vladimir Smyslov, Elena Scutelnic, **PhD students:** Vladimir Boian, Anton Iacunin, Victor Suman, Maria Lupu , **Master students:** Cezar-Casian Malcoci, Andrei Sirbu,Vlad Topa, Cristian Glodeanu, Diana Nirca, Igor Ceban, Dinu Sirbu.
From Uni-TWENTE, The Netherlands - 10 persons:
Prof. Alexander Golubov, Prof. Valerii Vinokur, Prof. Alexander Brinkman, Prof. Wilfred van der Wiel, Prof. Hans Higenkamp, Dr. Vladimir Kogan, Dr. Igor Makhotkin, Dr. Joachim Woitok, **PhD students**: Tairzan Karabassov, Pim Reith.
From Stockholm University, Sweden – 8 persons:

Prof. Vladimir Krasnov, Dr. Taras Golod, Dr. Evgenii Borodianskyi, **PhD students**: Olena Kapran, Liese Morlet-Decarmin, Alexey Kalenyuk, Razmik Hovhanissyan, Adrian Iovan.

The official launch of the SPINTECH project took place on 20th September 2018 in the Ministry of Education, Culture and Research of the Republic of Moldova.

On Photo: Kick-off meeting on 20.09.2018 (Coordinator of "SPINTECH" Prof. A. Sidorenko, Minister Dr. M. Babuc, State secretary Dr. E. Belei)

On September 20th, 2018, the kick-off meeting for the SPINTECH project was held on the premises of the Ministry of Education, Culture and Research in Chișinău. The meeting saw the participation of Moldovan representatives of the project Advisory Board as well as of the Moldovan Minister of Education, Culture and Research Dr. Monica Babuc and the Secretary of State Dr. Elena Belei, who congratulated the Project Coordinator Prof. Anatolie Sidorenko for the acquisition of the project (Fig.1). The project received a total funding of 1 million € in the framework of the Twinning call of the EU H2020 Widening work programme, initially should have a total duration of 3 years (01.09.18 - 31.08.21), but was extended for 6 month in 2020, till 28.02.2022 due to the COVID-pandemic restrictions. As explained in his talk Coordinator of the project Prof. Sidorenko, SPINTECH aims at boosting the scientific excellence and innovation capacity in spintronics of the D. Ghiţu Institute of Electronic Engineering and Nanotechnologies (IEEN) through collaboration and staff exchange with two highly experienced partners: the University of Stockholm in Sweden and the University of Twente in the Netherlands, which at the meeting were represented by Prof. Vladimir Krasnov and Prof. Alexander Golubov respectively. The implementation plan for the SPINTECH was presented by Prof. Anatolie Sidorenko while the general framework of the Twinning call was illustrated by Dr.Pepa Krasteva, EU Project Officer responsible for project monitoring.

As it was mentioned, the overall aim of the SPINTECH project is to boost the scientific excellence and innovation capacity in the field of spintronics – especially in the

development of advanced technology for design and production of superconducting spin-valves of the D. GHITU Institute of Electronic Ingineering and Nanotehnologies of Moldova and its high-experienced Twinning partners: Stockholms Universitet in Sweden (SU) and Universiteit Twente in the Netherlands (UTWENTE). To achieve this aim during the 3,5 years of the project, the partners implemented a research and innovation strategy with the following objectives:

Objective 1: Strengthen D. GHITU IE's research excellence in spintronics.

Objective 2: Enhance the research and innovation capacity of D. GHITU IE and the Twinning partners.

Objective 3: Raise the research profile of D. GHITU IE and the Twinning Partners.

Objective 4: Contribute to the research and innovation priorities of Moldova.

Objective 5: Support research and innovation on a European level.

Spintronics is a new, but a very important field of research and engineering exploiting the influence of intrinsic electron spin on electrical transport. It is a rapidly developing area that allows insight into fundamental spin-dependent physical properties and exponentially expanding practical applications — such as the read head sensors for hard drives and memory elements for computers of new generation – energy efficient computers with non-von Neumnn architecture, the brain-like Artificial Neural Networks (ANN). One of the main challenges in this field is the realization of spintronics based device; in particular, there is intense research activity focused on combining superconductivity and spintronics, to enhance device functionality and performance. In this framework, the objective was to strengthen D. GHITU IE's research excellence in superconducting spintronics by focusing efforts on two sub-topics with the support of the Twinning partners SU and UTWENTE:

1. Advanced vacuum technologies development for fabrication of layered nanostructures for spintronics (D. GHITU IE and SU), and
2. Elaboration and testing of a superconducting spin-valve for switching and memory elements (D. GHITU IE and UTWENTE)

For the achievement of that goals, the most important part of activities was staff-exchange visits for the knowledge transfers. It was done according to the grant agreement plan. The overview of that 3,5 years process is presented in the part 1 of this book.

1.1. Staff exchanges between D. GHITU IE and SU during Year1.
From D. GHITU IE to SU (Current total: 8.8 person-months; Planned: 7 person-months)

Researcher	Start Date	End Date	Duration [days]	Description
Roman Morari	01/11/2018	31/12/2018	61	Training on Clean Room, SEM, Ion beam etching, nanostructure manufacturing
Vladimir Boian	15/04/2019	15/06/2019	62	Training on equipment and software available at SU, development and study of experimental methods
Roman Morari	15/04/2019	15/06/2019	62	Research and study of stepwise resistive transitions in a zero magnetic field on a multilayer periodic sample
Anatoli Sidorenko	01/06/2019	25/07/2019	55	Training on characterisation of superconducting properties of Josephson junctions, dissemination activities, project management, participation and preparation of Jun 14 workshop.
Andrei Prepelitsa	14/06/2019	30/06/2019	17	Training on focused ion-beam lithography and characterisation of superconducting properties of Josephson junctions
Elena Condrea	10/06/2019	17/06/2019	8	Training on characterisation of superconducting properties of Josephson junctions, participation and preparation of Jun 14 workshop.

During Year 1, training and education of D GHITU IE researchers were focused on activities related to the individual objectives towards advanced vacuum technologies development for fabrication of layered nanostructures for spintronics (Sub-topic 1). As stated in the DoA, all staff exchanges followed the tasks previously detailed during the first year (M1-12) of SPINTECH project between D GHITU and SU.
In details the result – information and knowledge gained by the IEEN researchers during that visits is presented below.

R. Morari (01/11/2018 – 31/12/2018)

Objectives of the exchange visit done:

1. Clean Room study.
2. Learning the technology of preparing a multilayer sample and obtaining a pattern on its surface using positive photoresist.
3. To study in detail the etching process, as well as the types of etching by chemically active plasma.
4. Study of the technology of precision etching of the material with nanometer accuracy using a focused ion beam (FIB) process.
5. Using the knowledge gained, to prepare several structures of the Josephson junction according to planar technology and to measure the structures obtained at low temperatures in external magnetic fields.

Activities performed during the exchange visit:

1. The process of projection exposure with a resolution of up to 5 microns in fully manual and semi-automatic mode was studied and mastered.
2. The technologies of reactive-ion selective etching in a gas mixture of CF4: O2 and ion-plasma in Ar + were studied in detail using the “ICP / RIE Oxford Plasmalab System 100” in Institute of Alba Nova Physics, Stockholm. In the process of etching, methods for controlling the thickness of the etched material were studied, as well as methods for combating the subduing of the photoresist. The installation is controlled in a fully automatic mode, which minimizes the interaction of the operator with hazardous chemical compounds.
3. Practical skills were obtained on the FEI Nova 200 Dual Beam, equipped with a scanning electron microscope and a focused ion beam for precision etching of the material with nanometer accuracy. The ions, a Ga + source is used here. Thanks to the unique manipulator, the sample can rotate in all three planes and lock in any position without drift and critical vibrations. This equipment allows not only with nanometer accuracy to be positioned on the surface of the sample, but also to etch in clearly selected places without damaging adjacent areas. This unique opportunity was actively used in the preparation of Josephson junctions based on Nb / Co / Nb layered structures, where the electric current was passed through the cobalt ferromagnetic layer, and the electrical isolation of niobium was achieved by etching it from the end of the structure.
4. The structures of planar Josephson junctions based on Nb / Co / Nb films were obtained for further study of the behavior of the critical current in external magnetic fields.

5. Skills were obtained on complex cryogenic equipment assembled on the basis of the 'He3 / He4 Oxford Cryo System" dissolution refrigerator. The skills of assembling samples with nanoscale structures, preventing the formation of static electricity and unwanted discharges were worked out. Experience was gained in measuring the currents in the nano-ampere range, using electric filters to filter out spurious signals induced such as radio waves, power line noise, and many others; as well as the use of PXI-type wanted signal amplifiers. Here, I also made changes in the monitoring measurement program to add the ability of the remote control of the magnetic field, which made it possible to perform round-the-clock measurements regardless of the presence in the laboratory.

V. Boian (15/04/2019 – 15/06/2019)

At the University of Stockholm samples have been prepared (with the help of the Magnetron Z – 400), they had been processed according to a certain technological algorithm in order to be physically available for subsequent measurements. In order for the sample to be passed through the technological algorithm it is usually cut to 5mmx5mm. With the help of "Klayout 0.25.8" software, a special profile is drawn which is later printed (the method called "Lithography") on our sample. This profile appears differently from case to case depending on the purpose of the experiment and the accumulation of data as needed. Then we put the sample on the spinner (installation capable of rotating the sample) - the rotations start up to 4000 rpm, and the photoresist S1818 or S1813 is pipetted, after 1 min. rotations on the sample remain 1.8 µm thick photoresist, after which the sample is deposited on the electrical network and "baked" for 1 min at 100 ° C: At Smart Print, the negative is made on our sample and then we soak in the developer ME - 319 and hold the sample in it for 30 - 45 seconds until we notice that the sample has been cleaned and only our profile drawn using Klayout 0.25.8 software remains, if the sample cleaned it is necessary to wash it with H2O and blow it with N2.

The next technological step is: Engraving. In this process, the "eating" of the layers up to Si, Si2O3 takes place. When the sample gets the proper look it is glued to FOMBLIN RT 15 usually reads 4 samples on the rolling support of the PLASMALAB SYSTEM 100 installation.

We introduced the samples in CryeRIE where their cooling takes place to -50C for 10 minutes, after which the recording in the atmosphere of Ar takes place. For each material there are engraving recipes so depending on the thickness of the layers, the material and their number we calculate the total time of engraving not before calibrating the installation after time. After finishing the engraving process, the sample is heated to room temperature, so it is possible to work with the sample further. An important step in deciding that the sample was etched up to the Si or Si2O3 crystal is to verify the sample thickness in the Profilometer.

When the sample is ready, we proceed to attach it to the PCB port and the attachment is made using the BF6 glue. After fixing the crystal on the PSB port, the next technological step is the microcabling. When the microcabling is finished, this PCB port

is mechanically fixed to the socket that is introduced into the cryostat and then makes the electrical connection of the cryostat with our crystal (sample):
In the end - our sample of permanently processed crystal is introduced in the installation called: cryogenic installation. In the cryogenic installation our sample is cooled up to 0,4K, after which the scientific research program is carried out.
During this period (15.04.19 - 15.06.19) exchange of experience at AlbaNova University - Stockholm, I studied the magnetic software - OOMMF - Object Oriented MicroMagnetic Framework (Self-Magnetic Structure). This software proposes:
1. Automatic saving of scalar and vector fields.
2. Presents the previous values of the scalar outputs.
3. Displays the vector fields.
4. Displays X-Y charts.
5. View and edit problem for: mmSolved2D or Oxsii.
6. Solve X-Y planar problem.
7. Solve 3D space problem.
The software – "OOMMF works very stable and error free if it is installed on the Linux operating system.
Conclusion: The planned works for the study and development of the experimental methods developed at the University of Stockholm have been entirely completed - during the daily work in the university laboratories, as well as during the training workshop held on 14 June 2019 and to which I took part.

R. Morari (15/04/2019 – 15/06/2019)

Objectives: Research and study of stepwise resistive transitions in a zero magnetic field of a multilayer periodic sample.
Work done: Samples were prepared by magnetron deposition (Leybold Z-400 model) at room temperature and argon atmosphere (purity more than 99.999%, working pressure 8 × 10-3 mbar). The residual pressure in the spray chamber before deposition was about 2 × 10-6 mbar. The film deposition substrates (25 × 25 mm2) were cut from a commercial silicon (111) oriented plate. To prepare the structures, two sputtering targets were used: niobium with a purity of 99.99% and cobalt with a purity of 99.95%. Each type of SFS sample was prepared in one pass without pressure drop in the chamber. The growth rate of Nb is 3 nm / s, Co - 0.1 nm / s. For the measurement, we prepared several types of samples; the list is presented below. The list of samples presented in the work:
- Si-Sub // Nb (50) / Co (1.5) / Nb (8) / Co (2.5) / Nb (8) / Si-Cap, abbreviated notation: S- (F1S2F2S2) # 1;
- Si-Sub // Nb (50) / 3X [Co (1.5) / Nb (6) / Co (2.5) / Nb (6)] / Co (1.5) / Nb (6) / Si-Cap, abbreviated notation: S-SL3 (F1S2F2S2) -F1S2 # 3;
- Sa-Sub // Nb (150) / 3X [Co (1.5) / Nb (8) / Co (2.5) / Nb (8)] / Co (1.5) / Nb (250, abbreviated notation: S-SL3 (F1S2F2S2) -F1S # 1
In addition, test films were prepared from a single niobium film (thickness greater than 200 nm) to calibrate the rate of reactive ion etching of the samples. The etching technology of S / F / S and test samples differs only in an additional step for argon-

plasma removal of the intermediate cobalt layer. To create a pattern on the surface of Nb test films, we used the standard photoresist exposure technology (S1813) through a UV projector and the corresponding mask. To etch Nb samples, we used the Cryo RIE Albanova facility (KTH, Stockholm, Sweden). You will find the main details in the list:
- Gas mixture (CH4: O2 = 20: 1): CH4 - 40.0 units / O2 - 2.0 units;
- Gas pressure during the process: 80.0 mTorr;
- HF generator: 55 W;
- Plasma generator with inductive coupling: 200 W;
- Temperature: 300C.

After one minute of etching, the test samples were purified in acetone using an ultrasonic bath at room temperature for 3 minutes and dried in a stream of pure nitrogen. Etched niobium steps on the test samples were measured using a standard profiler setup, in the cantilever movement mode from the thicker side of the niobium to the thinner one. The obtained diagram shows the average result (measured at 6 or more different points) of the etching of the Nb test film for two types of substrates used as a sample holder - double-polished sapphire and quartz for two cases: with thermal paste (for better heat dissipation) and without.

The intermediate layer of Co was removed in an atmosphere of pure Ar at room temperature without forced cooling using liquid nitrogen. Thermal grease was applied in a thin layer between the sample and the holder substrate to prevent hard baking of the photoresist during the etching process. As can be seen from fig. 1 - heat transfer paste does not significantly affect the etching rate of the Nb film, therefore, we applied it at the very beginning of the process and the samples were etched from beginning to end without unnecessary actions and depressurization of the chamber. The main details of co-etching are listed below:
- Gas: pure Ar;
- Gas pressure during the process: 7.0 mTorr;
- HF generator: 300 W;
- Etching time: 5 min.

As noted, an ultrasonic bath was used to remove unexposed photoresist. In the case of hard calcination of the photoresist, the samples were purified in oxygen plasma for 5 min at an RF power of 100 W.

A sample glued to the contact pad with printed contacts; the contact pad with the sample is attached to the sample holder; the sample holder is fixed to the transport stand of the cryogenic chamber; assembly work of the entire structure.

The subsequent manipulations with the sample shows: a fresh sample is fixed with glue on special contact pads for subsequent desoldering and installation of current-carrying microwires using microwelding. The resulting circuit is attached to the sample holder, which must be moved inside the cryogenic installation for measurements. The movement is carried out using a brass tripod through a system of valves that ensure the closure and tightness of the measuring system.

Conclusions: During this working visit, we studied the manufacturing technology of a planar Josephson junction from a pre-prepared film structure based on superconducting niobium layers, as plates, and ferromagnetic pure cobalt.
In order to simplify the technology of ionic and chemical etching, independent experiments were conducted on the selection of parameters and materials for coarse etching of S / F / S film preforms of future nanostructured samples with a photoresist pattern. A number of own recommendations were developed here to simplify and seal the process.
Three-step superconducting transitions related to domain superconductivity were discovered for the first time in structures with triple repetition of [S2 / F1 / S2 / F2] - an integral part of the SL3 (F1S2F2S2) -F1S2 type supercross.
In this work, for the first time, we have shown the possibility of successful integration of superlattice structures based on thin films of ferromagnets and non-superconducting metals into superconducting Josephson junctions based on niobium films. The use of superlattice structures with two sets of coercive forces as a layer between superconducting electrodes makes it possible to additionally influence the sample and more “smooth”, adjustable and reproducible adjustment of the main conductive properties of the Josephson junction using an external magnetic field. Due to the combination of high magnetosensitivity of the structure, energy efficiency and the performance of superconducting Josephson junctions, our system can be used as the basis for future elements in the field of superconducting calculations and quantum control systems.

A. Sidorenko (01/06/2019 – 25/07/2019)

Planned for working visit:
1. Coordination of the research work of the Moldavian team in frame of the staff-exchange, planned for the period 15.04.2019 – 25.07.2019
2. Organization and participation in Working meeting and Training workshop in SU.
3. Editing of the book for SPINGER-edition.
4. Discussion of the obtained results of measurements of parameters of SFS-nanostructures and Josephson junctions.

According to the plan of the working visit, the following activities were performed:
1. Organisation and participation working meeting and training, at Stockholm University on 14.06.2019 (the program and list of participants with their signatures are attached).
2. Preparation and delivery of a presentation on “Advanced methods of nanostructures fabrication”.
3. Coordination of the research work of Vladimir Boian (worked in SU 15.04-15.06.2019), Roman Morari (worked in SU 15.04-15.0 6.2019), Elena Condrea (worked in SU 10.06-17.06.2019), and Andrei Prepelita (worked in SU 14.06-30.06.2019) – elaborated for their research “Working plan” and evaluation of the implementation of the plan and discussion of obtained results.
4. Preparation of the book for Springer edition: “Functional Nanostructures and Sensors for CBRN Defence and Environmental Safety and Security”, editors: Horst Hahn

and Anatolie Sidorenko. The final manuscript of the book, containing 20 chapters, was finalized in Stockholm during this staff-exchange visit.
Conclusion: During the working visit in frame of the SPINTECH project in Stockholm University, Prof. A. Sidorenko learned advanced methods for the investigation of superconducting properties of Josephson junctions, which will be implemented in D. GHITU IE in Chisinau.
A. Sidorenko also finalized the book preparation and sent the manuscript to SPRINGER Edition. He also coordinated the research work of 5 researchers from IIEN, working in the framework of staff-exchange visits in SU.

A. Prepelitsa (14/06/2019 – 30/06/2019)

Planned for working visit: Participation in Training workshop. Study of the FIB-lithography. Preparation of Josephson Junctions from layered SFS structures. Study of methods for Josephson junctions characterization. Measurements of parameters of SFS-Josephson junctions.
According to the plan of the working visit, the following activities were performed:
1. Participation in the Training Workshop in Stockholm University on 14.06.2019, listening to the lectures about modern advanced methods of nanostructures fabrication, characterization and investigation.
2. Training on methods of nano-sized samples preparation – Focusing Ion Beam lithography (FIB). I have learned this method from Dr. Taras Golod in Stockholm University, who gave lectures about FIB-method at the Training on 14.06.2019. On 17.06.19 I have discussed peculiarities of this method with Dr.Golod, and on 18.06.19 and 19.06.19 participated in preparation of the nano-sized SFS-Josephson junctions, using FIB –installation with Dr. Golod, under his supervision, in “clean room” of SU.
3. On 18.06-20.06.2019, preparation of electrical contacts to the SFS-Josephson junction, made from layered nanostructure “Substrate/Nb150nm/(Co1,5nm/Nb8nm/Co2,5nm/ Nb8nm/Co2,5nm)3 periods /Co1,5nm/Nb150nm “– with Dr. Golod, using the bonding-machine, and placed the prepared sample in the sample-holder for measurements.
4. Training on advanced methods of S-F-S Josephson junction characterization – under supervision of Dr. Taras Golod and Prof. Anatolie Sidorenko:
a) cryostat with superconducting solenoid for generation of magnetic field up to 8 Tesla, connected with the automated measuring system – measurements of the I-V characteristics for S-F-S Josephson junction;
b) “Shluise-system” with pipeline for evacuation of the sample holder - for rapid change and introduction of the sample-holder in the cold part of the cryostat.
5. During 21.06.19-28.06.measurement of I-V characteristics of the Josephson junction.
Conclusion: During the working visit in frame of the Staff-exchange of the SPINTECH project, in Stockholm University, A. Prepelitsa learned two new methods:
- focusing ion beam lithography;
- advanced methods of Josephson junctions characterization.
I-V characteristics in zero magnetic field and in applied external magnetic field of S-F-S Josephson junctions were investigated. The obtained results will be treated and fitted

for comparison with the theory of Kupriyanov-Klenov-Bakursky-Soloviev for preparation of publication.

E. Condrea (10/06/2019 – 17/06/2019)

Planned for working visit:

1. Participation in Training workshop
2. Study of advanced methods for Josephson junctions characterization.
3. Discussion of the obtained results of measurements of parameters of SFS-Josephson junctions.

According to the plan of the working visit, the following activities were performed:

1. Participation in the Training Workshop at Stockholm University on 14.06.2019, listening to the lectures about modern advanced methods of nanostructures fabrication, characterization and investigation of superconducting parameters of layered nanostructures and Josephson junctions.
2. Presentation "Bi Wires: properties in high magnetic field and under deformation" during the Training Workshop
3. Learning the modern method of investigation of superconducting samples and the Josephson junctions characteristics measurement, and discussed the results of investigation of S-F-S Josephson junctions.

Conclusion: During her working visit in frame of the Staff-exchange of the SPINTECH project in Stockholm University, E. Condrea learned advanced methods of superconducting properties of Josephson junctions investigation, which will be implemented in the Cryogenic Laboratory of D. GHITU IE in Chisinau.

1.2. Staff exchange from SU to D. GHITU IE: Researcher Activities

Researcher	Start Date	End Date	Duration [days]	Description
Vladimir Krasnov	04/03/2019	30/03/2019	26	Training on advanced vacuum technologies, dissemination and outreach activities, project management, participation to Mar 5 workshops.

V.M. Krasnov (04/03/2019 – 30/03/2019)

During that visit Prof. V.M. Krasnov has participated in organization of the Working Meeting and Training Workshop (05-06 March 2019, in Chișinău, Moldova). He participated in discussions with young researchers from D. GHITU IE and leading scientists from several Institutes of the Academy of Sciences of Moldova, participated in Training Workshop (Institute of Applied Physics, Institute of Mathematics, Institute of Chemistry). Together with project partners, he participated in the TV program "Stiinta si Inovare" on Moldova 1, explaining the goals of the SPINTECH project and the reasons of collaboration with Moldova in superconducting spintronics. Together with Prof. A. Sidorenko and Prof. A.A. Golubov, he made a presentation for students of N. Gogol Physics and Mathematics Gymnasium N37 of Chișinău, in which he presented

perspectives and challenges meeting young researchers in the beginning of their career. During this stay V. Krasnov visited Institute of Electronic Engineering and Nanotechnologies and learned new advanced vacuum technology for layered nanostructures fabrication, elaborated and patented by D. GHITU IE.

1.3. Staff exchanges between D. GHITU IE and UTWENTE during Year 1

From D. GHITU IE to UTWENTE (Current total: 2.8 person-months; Planned: 6 person-months)

Researcher	Start Date	End Date	Duration [days]	Description
Anatoli Sidorenko	28/10/2018	10/11/2018	14	Training on SQUID microscopy, dissemination activities, project management
Evghenii Andropov	03/11/2018	10/11/2018	8	Training on SQUID microscopy, attendance to lectures
Anatoli Sidorenko	31/07/2019	30/08/2019	31	Training on SQUID microscopy, dissemination activities, project management, participation to Aug 27 workshop.
Evghenii Andropov	31/07/2019	30/08/2019	31	Training on SQUID microscopy, dissemination activities, participation to Aug 27 workshop.

1.4. Staff exchange from UTWENTE to D. GHITU IE

Current total: 0.9 person-months; Planned: 4 person-months

Researcher	Start Date	End Date	Duration [days]	Description
Alexander Golubov	04/03/2019	30/03/2019	26	Training on advanced vacuum technologies, dissemination and outreach activities, project management, participation to Mar 5 workshops.

1.5. Description of the education, training and knowledge exchange during year 1

During Year 1, the visits, training and education of D GHITU IE researchers were directed to the activities related the objectives "Elaboration and testing of a superconducting spin-valve for switching and memory elements" (research sub-topic 2). As stated in the DoA, all staff exchanges followed the tasks previously detailed for the first year (M1-12) of SPINTECH between D GHITU and UTWENTE.

Education in methods of design and optimization of spintronic devices

• Training in high-resolution SQUID-magnetometry.

• Knowledge exchange in principles and methods of low temperature physics.

Between M1-12, DGHITU IE researchers who travelled to UTWENTE expanded their knowledge in several aspects of Research subtopic 2. They were trained in the principles of high-resolution SQUID microscopy and SQUID-microscope design, as well as the advanced methods of magnetic structures characterization and the methods of SQUID-microscopy developed in UTWENTE for characterization of layers and nanostructures of spin-valve. During their exchange visits to Moldova, UTWENTE researchers have learned from D.GHITU IE about the advanced vacuum technologies, elaborated in IE for thin films, nanostructures and layered magnetic metamaterials fabrication for spin-valve design.

The following section illustrates the work performed of the researchers from D.GHITU IE and UTWENTE during their exchanges. Each staff visit is detailed with the planned objectives and demonstrates the work carried out to achieve these items.

1.6. From D. GHITU IE to UTWENTE: Researchers activities

A. Sidorenko (28/10/2018 – 10/11/2018)

During the staff-exchange visit of the University of TWENTE (31.07.2019-30.08.2019), A. Sidorenko gained knowledge about novel methods of magnetic properties investigation using a specific SQUID-microscope, a unique piece of equipment developed by the laboratory of Prof. Alexander Golubov at UTWENTE. Together with A. Golubov, A. Sidorenko identified some important international conferences for participation during the first year of the project and discussed the content of workshops and trainings to be organized during the first year of the project (in Chisinau, 03-05 March 2019, in Stockholm University in June 2019, and in University of TWENTE in August 2019).

Together with Prof. A. Golubov and Prof. A. Brinkman, A. Sidorenko discussed the new results of investigation of superconducting nanonostructures for preparation of the draft of mutual publication- the chapter for "SPRINGER" book.

E. Andropov (03/11/2018 – 10/11/2018)

During the staff-exchange visit 03.11-10.11.2018 at UTWENTE, E. Andropov: (i) learned the design, parameters and possibilities of the unique installation – SQUID-microscope in the laboratory of Prof. Alexander Golubov; (ii) listened to lectures of Prof. Golubov in his laboratory about Spintronics and possible applications of the hybrid nanostructures Superconductor-Ferromagnet; and (iii) prepared the working plan for his next visit for

year 2019 and his participation in the organization of the SPINTECH-conference in Chisinau in 2019.

A. Sidorenko (31/07/2019 – 30/08/2019)

During the staff-exchange visit of the University of TWENTE (31.07.2019-30.08.2019), A. Sidorenko gained further knowledge about novel methods of magnetic properties investigation using the SQUID-microscope, a unique piece of equipment developed by the laboratory of Prof. Alexander Golubov at UTWENTE.

Also, together with staff at UTWENTE, A. Sidorenko elaborated the content and the program of the first international conference in frame of the project, to be organized in Chișinău (MD) at D. GHITU IE (SPINTECH -"NANO-2019: Limits of Nanoscience and Nanotechnologies", 24-27.09.2019) and of the first summer school ("SPINTECH Summer school "S/F Hybrid Structures for Spintronics", 27-30 September 2019, Chisinau, Moldova.) Finally, A. Sidorenko discussed with Prof. Golubov and Prof. Vinokur the new results of the investigation of SF-hybrid obtained during the staff-exchanges of D. GHITU IE staff (namely, A. Sidorenko, A. Prepelitsa, E. Condrea, R. Morari and V. Boian) during the period April – July 2019 at SU. Drafts of mutual publications and presentation for the "SPINTECH -NANO-2019" conference were also prepared.

E. Andropov (31/07/2019 – 30/08/2019)

During the visit 31.07-30.08.2019 at UTWENTE E. Andropov learned methods of magnetic properties investigation of layered Superconductor-Ferromagnet hybrid structures and Josephson junctions in the installation – SQUID-microscope, elaborated in Twente University. He has measured characteristics of the Josephson d-wave/s-wave junctions fabricated from d-wave superconductor YBa2Cu3O7-x (YBCO) and s-wave MoRe - alloy superconductor on the buffered MgO substrates. Basing on the results of this measurements, made together with member of the UTWENTE-team, Dr. Mikhail Faley, prepared the abstract for the publication "*Josephson junctions and pi-loops based on MoRe/YBa2Cu3O7-x*". The abstract of the report will be presented at the SPINTECH- conference „NANO-2019" in Chisinau, 24-27 September 2019. Also, E. Andropov participated in the Training Workshop "Magnetic properties investigation of SF-hybrid nanostructures", on 27 August 2019, at the University of Twente.

1.7. From UTWENTE to D. GHITU IE: Researcher Activities

A.A. Golubov (04/03/2019 – 30/03/2019)

During his stay in Moldova, Prof. A.A. Golubov helped organizing the Working Meeting and Training Workshop of 05-06/03/2019, in Chișinău (MD), with participation of young researchers from Moldova and leading scientists from Institutes of the Academy of Sciences (namely, Institute of Applied Physics, Institute of Chemistry, Institute of Mathematics) and Technical University of Moldova. Together with project partners, he participated in the TV program "Stiinta si Inovare" on Moldova 1, explaining the goals of the SPINTECH project and the reasons of collaboration with Moldova in superconducting spintronics. Together with Prof. A. Sidorenko and Prof. V. Krasnov, he gave a presentation of project SPINTECH to the students of the physico-mathematical

Gymnasium N37 (N. Gogol) of Chișinău. Finally, during his stay, Prof. Golubov learned a new advanced vacuum technology for layered nanostructures fabrication, elaborated and patented by D. GHITU IE.

1.8. Publications (year 1)

During Year 1, each SPINTECH consortium member has disseminated results related to the project's scientific themes. A list of journal articles acknowledging SPINTECH funding is reported below and include links to Open Access repository copies. In addition, several presentations (talks and/or posters) were given at international conferences and workshops. Details of these activities can be found in D2.1 ("Year 1 Report on Training Workshops, Conferences and Summer Schools", M12, UTWENTE).

1. Planar Superconductor-Ferromagnet-Superconductor Josephson Junctions as Scanning-Probe Sensors. T. Golod, O.M. Kapran, and V.M. Krasnov. Phys. Rev. Applied 11, 014062 (2019). https://arxiv.org/abs/1806.05582.
2. Periodic Co/Nb pseudo spin valve for cryogenic memory. N. Klenov, Y. Khaydukov, S. Bakurskiy, R. Morari, I. Soloviev, V. Boian, T. Keller, M. Kupriyanov, A. Sidorenko, and B. Keimer. Beilstein J. Nanotechnol. 10, 833–839 (2019). https://arxiv.org/abs/1809.10165.
3. Interplay of Magnetization Dynamics with a Microwave Waveguide at Cryogenic Temperatures. I.A. Golovchanskiy, N.N. Abramov, M. Pfirrmann, T. Piskor, J.N. Voss, D.S. Baranov, R.A. Hovhannisyan, V.S. Stolyarov, C. Dubs, A.A. Golubov, V.V. Ryazanov, A.V. Ustinov, and M. Weides. Phys. Rev. Applied. 11, 044076 (2019). https://arxiv.org/abs/1902.07566.
4. Memory-functionality superconductor/ferromagnet/superconductor junctions based on the high-Tc cuprate superconductors YBa2Cu3O7−x and the colossal magnetoresistive manganite ferromagnets La2/3X1/3MnO3+δ (X = Ca, Sr). R. de Andrés Prada, T. Golod, O. M. Kapran, E. A. Borodianskyi, Ch. Bernhard, and V. M. Krasnov. Physical Review B 99, 214510 (2019). https://arxiv.org/abs/1904.03951
5. Effects of the phase coherence on the local density of states in superconducting proximity structures. S.-I. Suzuki, A.A. Golubov, Y. Asano, Y. Tanaka. Physical Review B (submitted). https://arxiv.org/abs/1903.04178.
6. Ferromagnet/Superconductor Hybrid Magnonic Metamaterials. I.A. Golovchanskiy, N.N. Abramov, V.S. Stolyarov, P.S. Dzhumaev, O.V. Emelyanova, A.A. Golubov, V.V. Ryazanov, A.V. Ustinov. Adv. Sci. 6, 1900435 (2019). https://publikationen.bibliothek.kit.edu/1000096684.

2.1. Staff exchanges between D. GHITU IE and SU during Year 2

From SU to D. GHITU IE (Current total: 0.87 person-months)

Researcher	Start Date	End Date	Duration [days]	Description
Kapran Olena	22/09/2019	30/09/2019	9	Study of the advanced vacuum technology, elaborated in IEEN;

				participation in NANO-2019 conference; participation in Summer-school 27-30 September 2019 as scholar
Borodyanski Evgenii	22/09/2019	30/09/2019	9	Study of the advanced vacuum technology, elaborated in IEEN; participation in NANO-2019 conference; participation in Summer-school 27-30 September 2019 as scholar
Krasnov Vladimir	23/09/2019	30/09/2019	8	Study of the advanced vacuum technology, elaborated in IEEN; participation in NANO-2019 conference; participation in Summer-school 27-30 September 2019 as lecturer.

2.2. Staff exchanges between D. GHITU IE and UTWENTE during Year 2

From D. GHITU IE to UTWENTE (Current total: 4.67 person-months)

Researcher	**Start Date**	**End Date**	**Duration [days]**	**Description**
Sidorenko Anatolie	15/12/2019	12/01/2020	29	Study of the SQUID-microscopy methodology
Sidorenko Anatolie	22/02/2020	14/03/2020	22	Finalization together with Prof. A.Golubov the SPRINGER book for publication.
Antropov Evgheni	16/02/2020	14/03/2020	28	Study of the SQUID-microscopy equipment and experimental metods
Sidorenko Anatolie	02/07/2020	31/08/2020	61	Study of the novel methods of layered nanostructures characterization - SQUID microscopy for their implementation in the IEEN. Investigation of the magnetic properties of

				S/F hybrid nanostructures using SQUID.

2.3. Staff exchanges from UTWENTE to D. GHITU IE (Current total: 2.7 person-months)

Researcher	Start Date	End Date	Duration [days]	Description
Golubov Alexander	18/01/2020	10/02/2020	24	Study of the advanced vacuum technology, elaborated in IEEN;
Golubov Alexander	08/03/2020	28/03/2020	21	Study of the advanced vacuum technology, elaborated in IEEN; Discussion of the results of measurement of magnetic properties of the S/F samples obtained in January 2020
Golubov Alexander	04/07/2020	09/08/2020	36	Elaboration of the novel method of the S/F - interface transparency determination. Teaching of the IIEN team members in novel methods of the parameters estimation of superconducting switching elements. Organization of the training workshop in IIEN.

2.4. Publications (year 2)

During Year 2, each SPINTECH consortium partner has disseminated results related to the project's scientific topics. A list of journal articles acknowledging SPINTECH funding is reported below and includes links to Open Access repository copies. In addition, several presentations (talks and/or posters) were given at international conferences and workshops. Details of these activities can be found in the deliverable D2.2 "Year 2 Report on Training Workshops, Conferences and Summer Schools".

2.5. Books:

1. SIDORENKO Anatolie, HAHN Horst (the editors). Functional Nanostructures and Sensors for CBRN Defence and Environmental Safety and Security. Springer, Dordrecht,

2020, 320 p., DOI https://doi.org/10.1007/978-94-024-1909-2; ISBN 978-94-024-1908-5.

2.6. Chapters in books:

1. Alexander Penin, Anatolie Sidorenko. Transmission of Two Measuring Signals by an Invariant Property of Three Wire Communication Lines. Pages 65-82, In: SIDORENKO Anatolie, HAHN Horst (the editors). Functional Nanostructures and Sensors for CBRN Defence and Environmental Safety and Security. Springer, Dordrecht, 2020, 320 p., DOI https://doi.org/10.1007/978-94-024-1909-2; ISBN 978-94-024-1908-5
2. B. B. Banduryan, M. I. Bazaleev, V. F. Klepikov, V. V. Lytvynenko, V. E. Novikov, A. A. Golubov, A.S.Sidorenko. IR-Sensors and Detectors of Irradiation Based on Metal Folis.Pages 83-88. In: SIDORENKO Anatolie, HAHN Horst (the editors). Functional Nanostructures and Sensors for CBRN Defence and Environmental Safety and Security. Springer, Dordrecht, 2020, 320 p., DOI https://doi.org/10.1007/978-94-024-1909-2; ISBN 978-94-024-1908-5
3. A. Sidorenko, I. Rastimesina, O. Postolachi, V. Fedorov, T. Gutul, A. Vaseashta. The Toxic Effect of Trifluralin on Soil Microorganisms in the Presence of Fe0/PVP Nanoparticles. Pages 113-123. In: SIDORENKO Anatolie, HAHN Horst (the editors). Functional Nanostructures and Sensors for CBRN Defence and Environmental Safety and Security. Springer, Dordrecht, 2020, 320 p., DOI https://doi.org/10.1007/978-94-024-1909-2; ISBN 978-94-024-1908-5
4. M. Pajewska-Szmyt, R. Gadzała-Kopciuch, A. Sidorenko, Bogusław Buszewski. Smart Surface with Ferromagnetic Properties for Eco- and Bioanalytics. Pages 195-205. In: SIDORENKO Anatolie, HAHN Horst (the edotors). Functional Nanostructures and Sensors for CBRN Defence and Environmental Safety and Security. Springer, Dordrecht, 2020, 320 p., DOI https://doi.org/10.1007/978-94-024-1909-2; ISBN 978-94-024-1908-5.
5. Ashok Vaseashta, Gheorghe Duca, Elena Culighin, Oleg Bogdevici, Surik Khudaverdyan, Anatolie Sidorenko. Smart and Connected Sensors Network for Water Contamination Monitoring and Situational Awareness. Pages 283-296. In: SIDORENKO Anatolie, HAHN Horst (the editors). Functional Nanostructures and Sensors for CBRN Defence and Environmental Safety and Security. Springer, Dordrecht, 2020, 320 p., DOI https://doi.org/10.1007/978-94-024-1909-2; ISBN 978-94-024-1908-5.
6. Boguslaw Buszewski, Viorica Railean Plugaru, Pawel Pomastowski, Anatoli Sidorenko. Silver Nanoparticles: Synthesis, Characteristics, and Application. pages 432-449. In: Handbook of Research on Emerging Developments and Environmental Impacts of Ecological Chemistry. Gheorghe Duca and Ashok Vaseashta (The editors), Global, Hershey, PA USA, 649 pages. ISBN13: 9781799812418, ISBN10: 1799812413, EISBN13: 9781799812432, DOI: 10.4018/978-1-7998-1241-8

2.7. Articles:

1. Vakhrushev, A.V.; Fedotov A.Yu.; Savva Yu.B.; Sidorenko A.S. The simulation of processes for forming a superconductor spin valve based on the “superconductor-

ferromagnetic" nanostructure. Chemical Physics and Mesoscopic. 2019, 21, 362-374. doi: 10.15350/17270529.2019.3.38
2. Sidorenko A.S.; Boian V.; Savva Yu.B.; Fedotov A.Yu.; Vakhrushev, A.V. Functional nanostructures superconductor-ferromagnet for spintronics. Proceedings of the International Symposium Nanophysics and Nanoelectronics. 2020, 1, 114-115
3. Vakhrushev A.V.; Fedotov A.Yu.; Savva Yu.B.; Sidorenko A.S. Modeling the processes of atom structure formation of a superconducting spin valve. PNRPU Mechanics Bulletin, 2020, 2,16-27. DOI: 10.15593/perm.mech/2020.2.02
4. O. M. Kapran, A. Iovan, T. Golod, and V. M. Krasnov. Observation of the dominant spin-triplet supercurrent in Josephson spin valves with strong Ni ferromagnets. Phys. Rev. Research 2, 013167 (2020). Published 18 February 2020; DOI:https://doi.org/10.1103/PhysRevResearch.2.013167
5. Vasily S. Stolyarov, Dmitry S. Yakovlev, Sergei N. Kozlov, Olga V. Skryabina, Dmitry S. Lvov, Amir I. Gumarov, Olga V. Emelyanova, Pavel S. Dzhumaev, Igor V. Shchetinin, Razmik A. Hovhannisyan, Andrey M. Kokotin, Walter V. Pogosov, Valery V. Ryazanov, Mikhail Yu. Kupriyanov, Alexander. A. Golubov, Dimitri Roditchev. Josephson current mediated by ballistic topological states in Bi2Te2.3Se0.7 single nanocrystals. Communications Materials 1, 38 (2020). (Published: 02 July 2020) https://doi.org/10.1038/s43246-020-0037-y
6. T. Karabassov, V. S. Stolyarov, A. A. Golubov, V. M. Silkin, V. M. Bayazitov, B. G. Lvov, and A. S. Vasenko. Competitive 0 and π states in S/F/S trilayers: Multimode approach. PHYSICAL REVIEW B 100, 104502 (2019). Published 3 September 2019; DOI: 10.1103/PhysRevB.100.104502
7. Akihiro Sasaki, Satoshi Ikegaya, Tetsuro Habe, Alexander A. Golubov, and Yasuhiro Asano. Josephson effect in two-band superconductors. PHYSICAL REVIEW B 101, 184501 (2020). Published 4 May 2020; DOI: https://doi.org/10.1103/PhysRevB.101.184501.

3.1. Staff exchanges between D. GHITU IE and SU during Year3 (M25-M42)

During this period, training and education of D. GHITU IE researchers were focused on modern methods, developed in University of Stockholm - study of the ultra-low temperature new equipment experimental set up "OXFORD Instruments", learning methods of measurements learning of novel methods of measurements of superconducting properties of nanostructures, measurements of the Josephson Junctions with ferromagnetic weak link made from artificial magnetic metamaterials, with the aim of implementation them in superconducting spintronics and for design of base elements for artificial neural networks.

8 collaborators of IEEN during 12 staff-exchange have increased their experimental level and more general – the scientific level in superconducting spintronics and in advanced methods of fabrication and measurements of the properties of superconducting functional nanostructures. They participated in the research work in clean room, learning the high-resolution photolithography, precise nano-milling of the functional nanostructures – S/F/S Josephson Junctions by Focused Ion Beam treatment

(FIB) of the multilayers, and novel techniques in low-temperature measurements of superconducting characteristics of the Josephson Junctions on the ultra-low temperature equipment "Oxford Instruments". Collaborators of IEEN, together with colleagues from SU, participated in several training workshops, summer schools and winter schools, organized by Prof. V.Krasnov and Prof. A.Sidorenko in SU, listened to a lot of excellent lectures about superconducting functional nanostructures – spin-valves, FIB-milling of the nanostructures, base elements of superconducting spintronics. As the result of that staff-exchange visits, IEEN collaborators gained new knowledge and transferred it to the IEEN, boosting of it's excellence in all aspects of spintronics. For this purpose served also staff-exchange visits of 3 SU collaborators, worked in IEEN in 2020-2021. In particular, Prof.Vladimir Krasnov gave a number of very useful lectures abour various aspects of Spintronics. Also he prepared together with Prof. Anatolie Sidorenko the second SPINTECH conference in Moldova in September-2021 with participation of leading experts in Spintronics from 16 countries and some SPINTECH-Schools. Detailed information about that SPINTECH- conference and Schools is presented in D.2.3.

3.2. Staff exchange From D. GHITU IE to SU

Current total: 10 person-months

Anatoli Sidorenko	1-Apr-21	30-May-21	60	Organization of the Summer School, presentation of lectures at the Summer School; study of the new equipment –ultra-low temperature experimental set up "OXFORD Instruments", learning methods of measurements.
Anatoli Sidorenko	23-Jan-22	8-Feb-22	17	Organization of the Winter SCHOOL and presentation of lecture; Study of superconducting properties of Nb/Co nanostructures prepared in IEEN, on the ultra-low temperature experimental set up.
Evghenii Antropov	25-May-21	30-Jun-21	37	Learning the method of nano-sized samples preparation – Focusing Ion Beam lithography (FIB). I listening to

				the lectures about precise methods at the Summer School on 28.05.2021.
Andrei Prepelita	2-May-21	30-Jun-21	60	Organization of the Summer School "Brain-like Artificial Neural Network: Superconducting Spintronic's Alternative"; Learning the ultra-low temperature equipment "Oxford Instruments", the automated measuring system for measurements of the I-V characteristics of Josephson junctions, and advanced methods of S-F-S Josephson junction characterization.
Elena Condrea	22-May-21	31-May-21	10	Learning the ultra-low temperature equipment "Oxford Instruments", the automated measuring system for measurements of the I-V characteristics of Josephson junctions, and advanced methods of S-F-S Josephson junction characterization.
Elena Condrea	2-Feb-22	28-Feb-22	7	Participated in the training on the set up "OXFORD Instruments" and learning of novel methods of measurements of superconducting properties of nanostructures.
Vladimir Boian	22-May-21	26-Jun-21	36	Learning the ultra-low temperature equipment "Oxford Instruments", the automated measuring system for measurements of the I-V characteristics of Josephson junctions, and advanced methods of S-F-S Josephson junction characterization.
Vladimir Boian	2-Feb-22	22-Feb-22	21	Investigation of

				superconducting properties of Nb/Co layered nanostructures. Participation in the Winter School.
Vladimir Fiodorov	22-May-21	10-Jun-21	20	Studying the photolithographic process on the SMART-PRINT installation and performing all technological manipulations to prepare the nanostructured samples.
Cezar Malcoci	2-Feb-22	22-Feb-22	21	Participated in the training on the set up "OXFORD Instruments", learning of novel methods of measurements of superconducting properties of nanostructures, measurements of the Nb/Co/Nb Josephson Junctions.
Lilia Bujor	6-Feb-22	28-Feb-22	23	Participated in the training on the set up "OXFORD Instruments", learning of novel methods of measurements of superconducting properties of nanostructures, measurements of the Nb/Co/Nb Josephson Junctions.
Anton Iacunin	8-Feb-22	28-Feb-22	21	Participated in the training on the set up "OXFORD Instruments", learning of novel methods of measurements of superconducting properties of nanostructures, measurements of the Nb/Co/Nb Josephson Junctions.

On Photos: Prof. A.Sidorenko with IEEN collaborators by training at the ultra-low temperatures installation "OXFORD Instruments" in Stockholm University.

3.3. Staff exchange from SU to D. GHITU IE

Current total: 5 person-months

Evgenii Borodianskyi	22.09.2019	30.09.2019	9	Participation in Nano-2019 conference and SPINTECH summer school
Olena Kapran	22.09.2019	30.09.2019	9	Participation in Nano-2019 conference and SPINTECH summer school
Vladimir Krasnov	22.09.2019	01.10.2019	10	Participation in Nano-2019 conference and SPINTECH summer school
Vladimir Krasnov	12.09.2020	04.10.2020	23	Preparation of the manuscript within the project, based on results obtained by Swedish and Moldavian researchers during previous visits of Moldavian partners to Stockholm University. As a result of this visit, the manuscript has been written and was submitted to Phyical Review B.
Vladimir Krasnov	07.11.2020	08.12.2020	28	The main purpose and outcome of this visit was a scientific collaboration with the Institute of Electrical

				Engineering and Nanotechnologies of the Moldavian Academy of Sciences. The central activities were the advisory board meeting and preparation of two scientific articles within the SPINTECH collaboration.
Vladimir Krasnov	27.02.2021	27.03.2021	29	Scientific collaboration with the Institute of Electrical Engineering and Nanotechnologies in development of the advanced vacuum processes of nanostructures for spintronics fabrication. Preparation to the (second) SPINTECH in September 2021 and finalizing of two scientific articles within the project collaboration, one of which is published in Phys.Rev.B 103, 094509 (2021).
Vladimir Krasnov	18.09.2021	14.10.2021	26	Preparation togethere with A. Sidorenko “The 12th International Conference on Intrinsic Josephson Effect and Horizons of Superconducting Spintronics and participation in the conference with lecture. Participation in the Stearing Committee meeting and Advisory Board meeting.

On Photo: Prof. V.Krasnov (first links) in Cryogenic Laboratory IEEN by knowledge exchange in advanced technology of magnetron sputtering, March 2021

3.4. Staff exchange between D. GHITU IE and UTWENTE during Year3 (M25-M42)

During this period, training and education of D. GHITU IE researchers were focused on modern methods of nanostructures characterization with high resolution, developed in University of Twente - 8 collaborators of IEEN during 18 staff-exchange working visits in the University of Twente gained new knowledge, increasing their scientific capacity learning novel advanced methods of nanostructures characterization at a number of trainings and training workshops:

- Participants learned the high-resolution XRD equipment "X'Pert -PRO" of the PANalytical company, diffractometery of high resolution and gained the novel XRD methods of nanostructrures characterization.
- Training of participants in Confocal Microscopy, learning of construction of the confocal microscope and methods of measurements using that equipment;
- Training in new precise methods of nano-layered structures investigation in the high-sensitive SQUID-microscope, investigating magnetic properties of the nanostructures
- learning advanced methods of multilayered structures fabrication and their characterization in the Thin Films Fabrication Center of University of Twente.

Participating in the Summer Schools and Winter Schools in Uni-Twente, the IEEN collaborators listened to a number of excellent lectures about Artificial Neural Networks, their design, characterization, base elements and abour spintrobics in general. Also several our-reach activity events were organised in Twente for extention of the general level of the participants. More detals about that events, winter and summer schools are given in the part D2.3.

3.5. Staff exchange from D. GHITU IE to UTWENTE

Current total: 12 person-months

Anatoli Sidorenko	29-Sep-20	28-Oct-20	30	Organized together the Summer School "Hybrid Structures for Spintronics and Qubits"; have learned the novel high-tech equipment, installed in the TWENTE University – Confocal Microscope and learned methods of nano-layered samples precise characterization.
Anatoli Sidorenko	22-Dec-20	22-Jan-21	32	Learned the precise equipment, modified SQUID Microscope, and novel methods, adjusted for measurements of magnetic properties of layered magnetic metamaterials
Anatoli Sidorenko	16-Jun-21	31-Aug-21	77	Organized learning of the modern equipment and measurment methods by the IIEN collaborators: X-ray diffractometer with high resolution "X'Pert -PRO" with the remote mode - automated measurements of the XRD- characteristics of layered nanostructures.
Anatoli Sidorenko	30-Sep-21	16-Nov-21	48	Have done measurements of magnetic state of spintronic nanostructures Nb/Co, using the SQUID-microscope. Learned new methods of calculation and modelling of the layered nanostructures, discussed with Prof. Alexander Golubov obtained results, prepared two articles for special BJN volume.

Anatoli Sidorenko	18-Dec-21	15-Jan-22	29	Prepared all necessary materials together with prof. A Golubov for the Winter School "Functional nanostructures – modelling, design, characterization"; Investigated resistive transitions of the Nb/Co nanostructures, prepared in IEEN for determination of Tc and Hc2 of the samples.
Anatoli Sidorenko	9-Feb-22	27-Feb-22	19	Organization of study and training in novel methods of diffractometry and Investigation of the nanostructures Nb, Nb/Co by XRD diffractometry
Evghenii Antropov	9-Jul-21	15-Jul-21	7	Learned the method of diffractometry of layered structures. investigations by XRD method, listened to the lectures about this method of nanostructures investigation. Learned advanced methods of magnetic properties investigation of magnetic samples in the installation – SQUID-microscope.
Evghenii Antropov	10-Nov-21	16-Nov-21	7	Learned the precise methods of nano-layered structures investigation in the high-sensitive SQUID-microscope, have done measurements of magnetic state of spintronic nanostructures Nb/Co.
Andrei Prepelita	29-Sep-20	28-Oct-20	30	Learned the novel precise methods of nano-layered samples characterization, using Confocal Microscope.
Andrei Prepelita	9-Jul-21	8-Aug-21	31	Learned the XRD equipment "X'Pert -PRO", X-ray diffractometer of high resolution, and learned

				advanced methods of spintronics-samples characterization.
Andrei Prepelita	10-Oct-21	10-Nov-21	31	Investigation of the samples in the remote mode - automated measurements of the XRD- characteristics of layered nanostructures superconductor-ferromagnet (Nb/Co), prepared in IIEN "D.GHITU".
Andrei Prepelita	9-Feb-22	27-Feb-22	19	Learned the novel precise methods of nano-layered samples characterization, using diffractometry; learned the novel advanced methods of nano-layered samples fabrication in the Thin Films Fabrication Center of University of Twente.
Oleg Bujor	10-Nov-21	16-Nov-21	7	New precise methods of nano-layered structures investigation in the high-sensitive SQUID-microscope has been studied.
Oleg Bujor	9-Feb-22	28-Feb-22	20	Learned the novel precise methods of nano-layered samples characterization, using diffractometry; learned the novel advanced methods of nano-layered samples fabrication in the Thin Films Fabrication Center of University of Twente.
Elena Condrea	10-Nov-21	16-Nov-21	7	Participated in the Training Workshop "Artificial Neural Networks – design, characterization, base elements"; learned the precise methods of nano-layered structures investigation in the high-sensitive SQUID-microscope.

Cezar Malcoci	10-Nov-21	16-Nov-21	7	Learned the functionality of nanoelectronic devices in deep-learning mode, and the SQUID microscope, learning methods of investigation the magnetic properties of materials.
Andrei Sîrbu	10-Nov-21	16-Nov-21	7	Learned the functionality of nanoelectronic devices in deep-learning mode, and the SQUID microscope, learning methods of investigation the magnetic properties of materials.
Vladimir Boian	10-Nov-21	16-Nov-21	7	Learned the functionality of nanoelectronic devices in deep-learning mode, and the SQUID microscope, learning methods of investigation the magnetic properties of materials.


On Photo: Prof. A.Golubov organized training of the IEEN collaborators on XRD Diffractometer "X'Pert PRO" for learning of the high-resolution XRD characterization of the samples (links), and training on SQUID-microscope (rights), July 2021.

3.6. Staff exchange from UTWENTE to D. GHITU IE

Current total: 7 person-months

Alexander Golubov	10.09.20	30.09.20	20	Participation in Nano-2019 conference and SPINTECH

				summer school. Lectures on the physics of supoerconductor-ferromagnet hybrid structures. Discussion of the results of experimetal investigation of theSF-hybrids with IEEN collaborators. Elaboration of the theoretical model
Alexander Golubov	15.11.20	05.12.20	20	Scientific collaboration with the Institute of Electrical Engineering and Nanotechnologies in theoretical analysis of the experimental data obtained. Preparation of a joint manuscript of the article for publication.
Alexander Golubov	20.03.21	13.04.21	24	Lecture course on the physics of triplet states in supoerconductor-ferromagnet hybrids.
Alexander Golubov	01.08.21	01.09.21	31	Scientific collaboration with the Institute of Electrical Engineering and Nanotechnologies in development and modelling of spin valve structures. Preparation of a joint paper manuscript
Alexander Golubov	15.11.21	06.12.22	22	Lectures and seminars on theoretical aspects of an odd-frequency pairing in superconducting hybrid structures.
Alexander Golubov	03.01.22	20.01.2022	18	Scientific collaboration with the Institute of Electrical Engineering and Nanotechnologies in development of memory elements in superconducting networks

				for artificial intelligence.
Alexander Golubov	14.02.22	28.02.22	15	Participation at a joint workshop **"Artificial Synapses for Spintronics"** with the Institute of Electrical Engineering and Nanotechnologies. Lectures on the physics of unconventional superconductivity and its applications. Discussion of the concept for a possible follow-up project.
Valery Vinokur	21.11.21	21.12.21	31	Lecture course on superconducting quantum networks based on high temperature superconductors.
Valery Vinokur	14.02.22	28.02.22	15	Participation at a joint **workshop "Artificial Synapses for Spintronics" with the Institute of Electrical Engineering and Nanotechnologies.** Preparation of a joint article.

3.7. Publications

During M25-M42, each SPINTECH consortium member has disseminated results related to the project's scientific themes. A list of journal articles acknowledging SPINTECH funding is reported below and include links to Open Access repository copies. In addition, several presentations (talks and/or posters) were given at international conferences and workshops. Details of these activities can be found in D2.3 ("Year 3 Report on Training Workshops, Conferences and Summer Schools", M42, UTWENTE).

3.8. Articles

1. Observation of the dominant spin-triplet supercurrent in Josephson spin valves with strong Ni ferromagnets. O. M. Kapran, A. Iovan, T. Golod, and V. M. Krasnov. Phys. Rev. Research 2, 013167 (2020), DOI: 10.1103/PhysRevResearch.2.013167.
2. Direct Visualization of Phase-Locking of Large Josephson Junction Arrays by Surface Electromagnetic Waves. M.A. Galin, F. Rudau, E.A. Borodianskyi, V.V. Kurin, D. Koelle, R. Kleiner, V.M. Krasnov, and A.M. Klushin, *Phys. Rev. Appl.* 14, 024051 (2020).
3. Crossover between short- and long-range proximity effects in superconductor/ferromagnet/superconductor junctions with Ni-based ferromagnets.

KAPRAN, O. M.; GOLOD, T.; IOVAN, A.; SIDORENKO, A. S.; GOLUBOV, A. A.; KRASNOV, V. M. *Phys.Rev* B. 2021, 103, 094509. DOI:10.1103/PhysRevB.103.094509 (IF: 3.575).
4. Theoretical Basis of Quantum-Mechanical Modeling of Functional Nanostructures. FEDOTOV, A.; VAKHRUSHEV, A; SEVERYUKHINA, O.; SIDORENKO, A.; SAVVA, YU.; KLENOV N.; SOLOVIEV, I. *Symmetry* 2021, 13, 883. https://doi.org/10.3390/sym13050883 (IF: 2.7).
5. Synthesis of nZVI/PVP nanoparticles for bioremediation applications. SIDORENKO, A.; GUTUL, T.; DVORNIKOV, D.; MINE GÜL, Ş.; TUĞÇE, A.; GUTUL, E.; DIMOGLO, A.; VASEASHTA, A. *Bioremediation Journal*. 2021, 25 (2) DOI:10.1080/10889868.2021.1911922 (IF: 1.724)
6. Fractionally Quadratic Approximation and Invariant Properties of the Nickel Steel Carpenter 49 Magnetization Curve. PENIN, A.A.; SAVVA, Y.B.; SIDORENKO, A.S. *Russian Microelectronics.*2021,50(2),p. 126–135. https://doi.org/10.1134/S1063739721020074.
7. PENIN, A.; SIDORENKO, A. Normalized parameters of a magnetoresistive sensor in bridge circuits. *Moldavian Journal of the Physical Sciences.* 2021, 20 (1) pp. 94-104.
8. Chirality of Bloch domain walls in exchange biased CoO/Co bilayer seen by waveguide-enhanced neutron spin-flip scattering. L. R. Tagirov, R. Tidecks, S. Horn, B. Keimer. PHYS. REV. B 104, 174445 (2021). DOI: 10.1103/PhysRevB.104.174445.
9. In situ transport characterization of magnetic states in Nb/Co superconductor/ferromagnet heterostructures. Olena M. Kapran, Roman Morari, Taras Golod, Evgenii A. Borodianskyi,Vladimir Boian, Andrei Prepelita, Nikolay Klenov, Anatoli S. Sidorenkoand Vladimir M. Krasnov. *Beilstein J. Nanotechnol.* 2021, *12,* 913–923. https://doi.org/10.3762/bjnano.12.68.
10. Intrinsic Josephson Effect and Horizons of Superconducting Spintronics. The Editor: Anatolie Sidorenko. Proceedings of the 12th International Conference on Intrinsic Josephson Effect and Horizons of Superconducting Spintronics, 22-25 September 2021, Chisinau, Moldova: Abstract Book – Chişinău: S. n., 2021 (F.E.-P. "Tipografia Centrală"). – 87 p. ISBN 978-9975-47-215-9. 538.9:620.3(082) I-58.
11. Josephson current mediated by ballistic topological states in Bi2Te2.3Se0.7 single nanocrystals Vasily S. Stolyarov, Dmitry S. Yakovlev, Sergei N. Kozlov, Olga V. Skryabina, Dmitry S. Lvov, Amir I. Gumarov, Olga V. Emelyanova, Pavel S. Dzhumaev, Igor V. Shchetinin, Razmik A. Hovhannisyan1, Sergey V. Egorov, Andrey M. Kokotin, Walter V. Pogosov, Valery V. Ryazanov, Mikhail Yu. Kupriyanov, Alexander. A. Golubov, Dimitri Roditchev COMMUNICATIONS MATERIALS | (2020) 1:38 | https://doi.org/10.1038/s43246-020-0037-y | www.nature.com/commsmat.
12. Josephson effect in two-band superconductors Sasaki, Akihiro; Ikegaya, Satoshi; Habe, Tetsuro; Golubov, Alexander A.; Asano, Yasuhiro.
Physical Review B, 101(18), 184501. https://doi.org/10.1103/PhysRevB.101.184501
13. Quasiparticle spectrum of mesoscopic superconducting junctions with weak magnetization. S.Suzuki, A.A. Golubov, Y. Asano, Y. Tanaka. JPS Conf. Proc. 30, 011045 (2020).
14. Ultra-strong photon-to-magnon coupling in multilayered heterostructures involving superconducting coherence via ferromagnetic layers.I. A. Golovchanskiy, N. N.

Abramov, V. S. Stolyarov, M. Weides, V. V. Ryazanov, A. A. Golubov, A. V. Ustinov, M. Yu. Kupriyanov. Science advances 7(25) 2021. DOI: 10.1126/sciadv.abe8638.
15. Resonant Oscillations of Josephson Current in Nb-$Bi_2Te_{2.3}Se_{0.7}$-Nb Junctions.Vasily S. Stolyarov, Dimitri Roditchev, Vladimir L. Gurtovoi, Sergey N. Kozlov, Dmitriy S. Yakovlev, Olga V. Skryabina, Valerii M. Vinokur, Alexander A. Golubov. Advanced Quantum Technologies 5, 2100124 (2022) https://doi.org/10.1002/qute.202270031

3.9. Invited talks at international conferences

1. Hybrid Structures for Spintronics and Qubits. A.S.Sidorenko, Invited lecture at *SPINTECH summer school-2020* "Functional nanostructures for superconducting spintronics: smart technological approach", 01-03.10.2020. University of Twente, the Netherlands.
2. Layered nanostructures for superconducting spintronics. Anatolie Sidorenko, invited talk at 7th International Conference on Superconductivity and Magnetism – "ICSM-2021", 21st -27th October 2021, Bodrum, Turkey.
3. ADVANCED TECHNOLOGY of ACTIVE INFLUENCE on HAIL PROCESSES for SECURITY of FOOD PRODUCTION. Anatolie Sidorenko, Plenary Talk at 1st Lekantara Annual Conference on Natural Science and Environment (LeNS) on 30 September 2021, Jakarta, Indonesia.
4. Functional nanostructures with complex topology. Anatolie Sidorenko, Invited talk at On-line International conf. *"CMD2020GEFES - Condensed Matter", Madrid*, Espana, 03.09.2020.
5. Modeling of the vortex dynamics in long Josephson junction. Ruzhickiy V.I., Soloviev I.I., Bakurskiy S.V., Klenov N.V., Sidorenko A.S., Kupriyanov M.Yu, Stolyarov V.S. On-line talk at 12-16 April 2021, Matera, Italy. Proceedings of " *2021 IEEE 14th Workshop on Low Temperature Electronics (WOLTE)*, 2021, pp. 1-3, doi: 10.1109/WOLTE49037.2021.9555435.
6. Hybrid nanostructures superconductor-ferromagnet for superconducting spintronics. A S Sidorenko, R A Morari, V Boian, A A Prepelitsa, E I Antropov, Yu B Savva, A Yu Fedotov O Yu Sevryukhina and A V Vakhrushev. Proceedings of 2nd Virtual Congress on Materials Science & EngineeringTheme: Outlining the Importance of Materials Science for a Better Future, March 29 - 31, 2021, p.23. –On-line invited talk
7. Crossover in superconductor/ferromagnet/superconductor junctions with Ni based ferromagnets. A. S. Sidorenko, O. M. Kapran, T. Golod, A. Iovan, V. Boian, Yu. B. Savva, A. A. Golubov, and V. M. Krasnov. Proceedings of 3rd Virtual Congress on MATERIALS SCIENCE & ENGINEERING, SEP 27 - OCT 01, 2021, p.34.- On-line invited.
8. Nanostructures Superconductor/Ferromagnet for Superconducting Spintronics Anatolie Sidorenko, Roman Morari, Vladimir Boian, Evgeni Antropov, Andrei Prepelitsa, Yurii Savva, Nikolai Klenov, Igor Soloviev, Alexander Vakhrushev. Proceedings of The 12th International Conference on Intrinsic Josephson effect and Horizons of Superconducting Spintronics, *22-25 September 2021, Chisinau, Moldova, p. 43.*- Off-line invited talk.
9. Chirality of Bloch domain walls in exchange biased CoO/Co bilayer seen by

waveguide-enhanced neutron spin-flip scattering. Yu. Khaydukov, D. Lenk, V. Zdravkov, R. Morari, T. Keller, A. S. Sidorenko, L. R. Tagirov, R. Tidecks, S. Horn, B. Keimer. Proceedings of The 12th International Conference on Intrinsic Josephson effect and Horizons of Superconducting Spintronics, 22-25 September 2021, Chisinau, Moldova, p. 46. - Off-line invited talk.

10. Topological features of quantum magnetotransport in Bi1-xSbx ($0 \leq x \leq 0.2$) bicrystals. Fiodor Muntyanu, Vitalie Chistol, Elena Condrea and Anatolie Sidorenko. Proceedings of The 12th International Conference on Intrinsic Josephson effect and Horizons of Superconducting Spintronics, 22-25 September 2021, Chisinau, Moldova, p. 58.- Off-line talk.

11. Modeling of superconducting spin valve magnetic properties. O. Yu. Severyukhina, A.Yu., Fedotov, A.Yu. Salamatina, A.V. Vakhrushev, A.S. Sidorenko. Proceedings of The 12th International Conference on Intrinsic Josephson effect and Horizons of Superconducting Spintronics, 22-25 September 2021, Chisinau, Moldova, p. 60.-

12. Modeling of cluster ion beams implantation into a metal substrate. S.V. Suvorov, A.V. Vakhrushev, A.S. Sidorenko. Proceedings of The 12th International Conference on Intrinsic Josephson effect and Horizons of Superconducting Spintronics, 22-25 September 2021, Chisinau, Moldova, p. 67.- Off-line invited talk.

13. Colorimetric biosensor based on ZnO / ZnFe2O4 heterostructures. A.A. Sirbu, D. S. Nirca, T. D. Gutul, V. M. Fedorov and A. S. Sidorenko. Proceedings of The 12th International Conference on Intrinsic Josephson effect and Horizons of Superconducting Spintronics, 22-25 September 2021, Chisinau, Moldova, p. 68.- Off-line talk.

14. Synthesis of nZVI /PVP nanoparticles for bio – applications. A.S. Sidorenko, T. D. Gutsul, E. G. Coscodan. Proceedings of The 12th International Conference on Intrinsic Josephson effect and Horizons of Superconducting Spintronics, 22-25 September 2021, Chisinau, Moldova, p.82.- Off-line talk.

15. Study of a new generation of rockets for active influence on clouds. E.A. Zasavitsky, D. I. Karagenov and A. S. Sidorenko. Proceedings of The 12th International Conference on Intrinsic Josephson effect and Horizons of Superconducting Spintronics, 22-25 September 2021, Chisinau, Moldova, p.83.- Off-line talk.

16. Environmental aspects of long-term hail-suppression activities in Moldova. E. A. Zasavitsky, E. I. Potapov and A. S. Sidorenko. Proceedings of The 12th International Conference on Intrinsic Josephson effect and Horizons of Superconducting Spintronics, 22-25 September 2021, Chisinau, Moldova, p.84. Off-line talk.

4.1. D2.1 –Training Workshops, Conferences and Summer Schools - Year 1 (M1-M12)

Executive Summary

This chapter of the book provids details on the second important part of the project (belonging to the Work Package2) - participation to international conferences as well as the organisation of training workshops, conferences and summer and winter schools during Year 1 of project SPINTECH. From the beginning of the action (01.09.18), project members have held 3 workshops (in Chisinau on March 5th, 2019, in Stockholm on

June 14th, 2019 and in Twente on August 27th, 2019) and organised an international conference ("SPINTECH-NANO-2019: Limits of Nanoscience and Nanotechnologies" in Chisinau on September 24th – 27th, 2019) and a summer school ("S/F Hybrid Structures for Spintronics" in Chisinau on September 27th – 30th, 2019). Finally, in order to disseminate the project content and promote scientific studies in Moldova, a visit to the high school "N. Gogol" Nr.37 in Chisinau was organised in March 2019, and "Open Door Day" in D.GHITU IE with visit more than 80 school-children was done on 11th November 2019 with visits of laboratories and presentation of experiments.

4.2. Training Workshops

Three training workshops have been held during the first year of SPINTECH: one in Chișinău (MD) on March 5th, 2019 (focused on technical content but also on EU-Moldova scientific collaborations and possible opportunities for young Moldovan researchers), one in Stockholm (SE) on June 14th, 2019 (focused on nanofabrication techniques) and finally one in Enschede (NL) on August 27th, 2019 (focused on magnetic properties of SF-hybrid nanostructures)

Training Workshop in Chișinău (MD) on March 5th, 2019

The first training workshop in the context of SPINTECH took place in Chișinău (MD) on March 5th, 2019 on IEEN's premises. During the workshop, project partners presented their most recent research in the field of spintronics. Technical presentations were preceded by an introductory speech by Dr.Tatiana Moraru, Head of Department at MECC (Ministry of Education, Culture and Research of Moldova), who presented the current status of collaboration between Moldova and the EU in the field of scientific research and underlined the importance of such big EU project as SPINTECH for Moldova. Finally, a presentation about opportunities for young researchers in the context of the H2020 programme was given by Giulio Scocchi from Intelligentsia Consultants (Luxemburg), which supported IEEN and their partners during proposal preparation. Scientists from some other Institutes of the Moldavian Academy of Sciences (Institute of Applied Physics, Institute of Mathematics, Institute of Chemistry) and from Technical University of Moldova took part in the workshop.

Within the training workshop, participants visited the vacuum laboratory, where Prof. Anatolie Sidorenko and Dr. Roman Morari explained in detail the advanced technology of high-quality Nb films fabrication, elaborated and patented in D.GHITU IIEN, that has a visible impact: as wrote in his report after the staff-exchange visit to IE Prof.Akexander Golubov: "I have learned a new advanced vacuum technology for layered nanostructures fabrication, elaborated and patented in IEEN, Chisinau which will be useful also for University of Twente" (Fig.1a).

Training Workshop in Chișinău (MD) on March 5th, 2019

The first training workshop in the context of SPINTECH took place in Chișinău (MD) on March 5th, 2019 on IEEN's premises. During the workshop, project partners presented their most recent research in the field of spintronics. Technical presentations were preceded by an introductory speech by T. Moraru, Head of Department at MECC

(Ministry of Education, Culture and Research of Moldova), who presented the current status of collaboration between Moldova and the EU in the field of scientific research and underlined the importance of such big EU project as SPINTECH for Moldova. Finally, a presentation about opportunities for young researchers in the context of the H2020 programme was given by G. Scocchi from Intelligentsia Consultants (LU), which supported IEEN and their partners during proposal preparation. Scientists from some other Institutes of the Moldavian Academy of Sciences (Institute of Applied Physics, Institute of Mathematics, Institute of Chemistry) and from Technical University of Moldova took part in the workshop.

Within the training workshop, participants visited the vacuum laboratory, where Prof. A.Sidorenko and Dr. R.Morari explained in detail the advanced technology of high-quality Nb films fabrication, elaborated and patented in D.GHITU IIEN, that has a visible impact: as wrote in his report after the staff-exchange visit to IE Prof.A. Golubov: "I have learned a new advanced vacuum technology for layered nanostructures fabrication, elaborated and patented in IEEN, Chisinau (Fig.1a)".

Fig. 1a (left) – advanced vacuum technology for layered nanostructures fabrication in IEEN, Chisinau, learned by the workshop participants; 1b (right panel) –opening of the workshop on 5th March 2019.

All participants gained new knowledge in advanced vacuum technology through this training workshop, which has increased their professional and academic capacities in this domain, and their individual career paths. This is in direct correlation fulfilling one of the main goals of the SPINTECH project in elaboration and fabrication of spin-valve. In total, 23 people participated during the first SPINTECH Training Workshop.

Following the Training Workshop, the SPINTECH project consortium members (A.S. Sidorenko, V.M. Krasnov and A.A. Golubov) visited the high school "N. Gogol" in Chisinau in order to disseminate the project content and promote scientific studies in Moldova.

Training Workshop in Stockholm (SE) on June 14th, 2019

The second training workshop in the context of SPINTECH project took place in Stockholm (SE) on June 14th, 2019 on SU's premises.

During the workshop, the research infrastructure of SU was illustrated to participants. Project members presented their most recent research related to ion beam photolithography, Bi wires and nanostructure fabrication. Technical presentations were given by both IEEN and SU members.

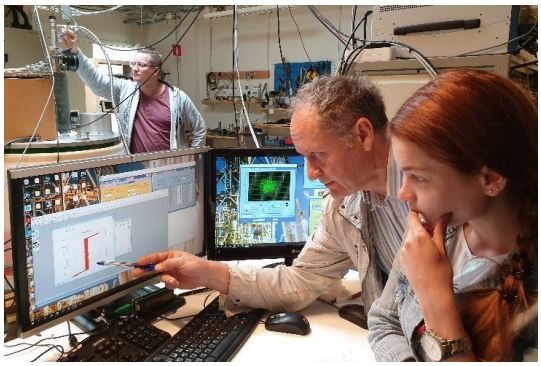
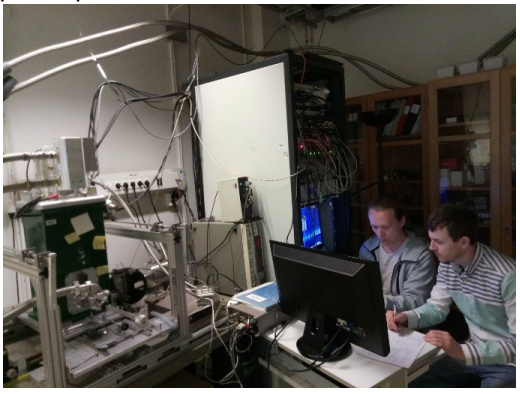
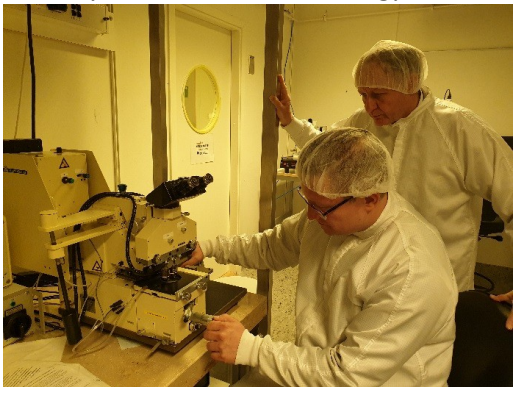



Fig.2a (right). Prof. Anatolie Sidorenko, Dr. Andrei Prepelitsa and PhD student Elena Kapran learning the advanced method of measuring of superconducting samples in SU. Fig.2b (left). Prof. Vladimir Krasnov presenting high-level resolution technique - Ion Beam Photolithography at the workshop on 14th June 2019 in SU.

In addition to ten participants from the SPINTECH partners (IE and SU), there were also nineteen participants from another Swedish institute: the Royal Institute of Technology. As they do not belong to the project, their list was not included in the initial report. Here, we provide the full list of participants from the Department of Applied Physics, Royal Institute of Technology. During the workshop on 14th June 2019, the research infrastructure of SU was illustrated to participants. Project members presented their most recent research related to ion beam photolithography, Bi wires and nanostructures fabrication. Technical presentations were given by both IEEN and SU members. 29 participants took part in the Workshop. In addition to ten participants from the SPINTECH partners (IE and SU), there were also nineteen participants from another Swedish institute: the Royal Institute of Technology.

Dr. R. Morari and PhD student V.Boian during low-tempearture experiment training (lefts). Dr. A. Prepelita and Prof. A.Sidorenko in clean-room at FIB training (rights).

The participation in that workshop of about 20 PhD Students and students from SU will help them in their career development within the frame of the SPINTECH project, gained from lectures given by Prof. A.Sidorenko, Prof. V.Krasnov, Dr. T.Golod and Dr. R.Morari, who presented a novel advanced technologies of nanostructures vacuum deposition (A.Sidorenko, R.Morari), ion-beam photolithography (T.Golod) and smart methods of nanostructures characterization (V.Krasnov). The variety of academic staff also means that PhD students involved in the research work on the SPINTECH project (E.Kapran, E. Borodianskyi) also benefitted from this event because they received direct feedback and input from experienced researchers. See Annex 2.2 for the Workshop Program.

Training Workshop in Enschede (NL) on August 27th, 2019

The third training workshop in the context of SPINTECH took place in Enschede (NL) on August 27th, 2019 on UTWENTE's premises. During the workshop, project partners presented their most recent research related to the investigation of magnetic properties of SF-hybrid nanostructures. Technical presentations were given by both IEEN and UTWENTE members.

Prof.A.Golubov and Prof.A.Sidorenko in SQUID lab.
Training workshop on SQUID-Microscopy in UTWENTE (links: A.Sidorenko, A.Golubov; rights: Pim Reith, A.Sidorenko, A.Antropov)

Lectures about smart methods of nanostructures characterization, using SQUID-microscopy, given by Prof. A.Golubov and Prof. V.Vinokur, increased the scientific capacity of the Dr. E.Antropov (IE), Dr. Pim Reith (UTWENTE) and PhD student Tairzhan Karabasov (UTWENTE), which has therefore increased their professional level and further them in their own career development.

4.3. Conferences

Members of the SPINTECH consortium have taken part in numerous conferences during the first year of the action, in order to disseminate their research on spintronics and to promote the SPINTECH project. Also, partners have already defined the international conferences which will take place in Chișinău before the end of the project. In Section 2.1, a complete list of conferences attended by SPINTECH members is reported. In Section 2.2, more details on the organisation of the international conferences are provided.

According to the Grant Agreement, it was planned that the consortium partners would attend various international conferences (Task 2.3: Participate in international conferences) - **such as:** MIFP-March Meetings in 2019 and 2020 in Rome, Italy, "Superconducting Hybrids" conference in San-Sebastian, Spain, in October 2018, European Conference on Applied Superconductivity EUCAS 2019, - to present research papers related to spintronics.

Participation of the project partners in the conferences was done under the personal invitations – with invited talks. Funding from H2020 project SPINTECH was acknowledged during all events, which served also as promotional opportunities for the project. By attending the international conferences, the project partners established new networks with other research organizations and companies for further preparation of new projects proposals. At the same time, was used that opportunity for the project results dissemination and information of the scientific society about SPINTECH project and its achievements.

Conferences and seminars attended by members of the SPINTECH project and titles of talks/presentations are provided in the Participation section to follow.

Conferences and seminars attended by members of the SPINTECH project and titles of talks/presentations are reported below. Funding from H2020 was acknowledged during all events, which served also as promotional opportunities for the project.

1. Direct Evidence of Proximity Induced Abrikosov Vortex Core in a Nonsuperconducting Metal. A.A. Golubov. Tunneling through Nanoscience (TTN) 2018 International Conference, 17-20 October 2018, Ravello (IT).

2. Static and dynamic properties of Josephson junctions with thin superconducting layer inside the weak link. A.A. Golubov. Tunneling through Nanoscience (TTN) 2018 International Conference, 17-20 October 2018, Ravello (IT).

3. Expansion of a superconducting vortex core into a diffusive metal. A.A. Golubov. Topological Materials Science Seminar (82), 3 December 2018, Kyoto (JP).

4. Profound surface superconductivity in conventional and unconventional superconductors, single crystals and thin films. V.M. Krasnov. XXIII Symposium on Nanophysics and Nanoelectronics, 11-14 March 2019, Nizhnij Novgorod (RU).

5. Superconductor-ferromagnet hybrid structures for artificial neural networks. N. Klenov. Invited seminar @IEEN. 27 March 2019, Chișinău (MD).

6. Functional Nanostructures Superconductor/Ferromagnet for Superconducting Spintronics. A. Sidorenko, A.A. Golubov, V.M. Krasnov, A. Wixforth, H. Hahn, Y. Savva, L. Tagirov, M. Kupriyanov. 30th World Nano Conference - Invention and Innovation of New Concepts in the Field of Nanotechnology, 20-21 May 2019, Zürich (CH). Invited talk "Functional Nanostructures Superconductor/Ferromagnet for Superconducting Spintronics" of A. Sidorenko at 30th World Nano Conference, 21 May 2019, Zürich.

7. Superconducting supercomputer: challenges and solutions. V.M. Krasnov. 30th World Nano Conference - Invention and Innovation of New Concepts in the Field of Nanotechnology, 20-21 May 2019, Zürich (CH).
8. *Superconductor/Ferromagnet Layered Nanostructures for Superconducting Spintronics*. A. Sidorenko, A.A. Golubov, V.M. Krasnov, A. Wixforth, H. Hahn, Y. Savva, L. Tagirov, M. Kupriyanov. BIT's 10th World Congress of Chemistry & Biology 2019, 22-24 May 2019, Barcelona (ES).
9. *Abrikosov vortex as a Josephson phase shifter*. V.M. Krasnov. Invited talk. VORTEX 2019 Workshop, Poster Session, 20-25 May 2019, Antwerp (BE).
10. *Josephson emission from Bi2Sr2CaCu2O8+δ mesa structures.* E.A. Borodianskyi and V.M. Krasnov, VORTEX 2019 Workshop, Poster Session, 20-25 May 2019, Antwerp (BE).
11. *Planar Jospehson junction as an element for novel superconducting devices*. T. Golod, O.M. Kapran, V.M. Krasnov, VORTEX 2019 Workshop, Poster Session, 20-25 May 2019, Antwerp (BE).
12. *S/F/S Josephson junctions with a strongly ferromagnetic Ni barrier*. O.M Kapran, T. Golod, A. Iovan, R. Morari, A. Sidorenko, A.A. Golubov, V.M Krasnov. VORTEX 2019 Workshop, Poster Session, 20-25 May 2019, Antwerp (BE).
13. *Coherent effects in junctions based on p-wave superconductors*. A.A. Golubov. International Workshop "Quantum Coherent Phenomena at Nanoscale 2019", 19-22 June, Ischia, Naples (Italy).

4.4. Organisation of the conferences

Following the workplan, consortium of the SPINTECH project have organised an international conference *"SPINTECH-NANO-2019: Limits of Nanoscience and Nanotechnologies"*, in Chișinău on September 24th – 27th, 2019, with participation of scientists from 15 countries.

The central goal of the SPINTECH-NANO-2019 Conference was to bring together leading experts from 15 countries to share their expertise and experience in developing of new ideas and principles in nanoscience and nanotechnologies, focusing on their novel implementations.

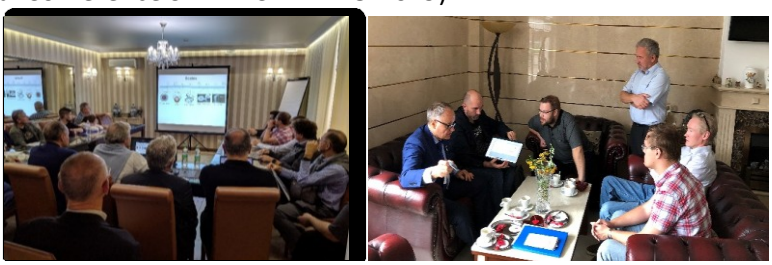
Participants of the "SPINTECH-NANO-2019: Limits of Nanoscience and Nanotechnologies" in Chisinau

Abstracts of the presented reports were printed in the abstract book (pdf. file is available on the SPINTECH web site), but the best presentations were selected and published in special issue of the Beilstein Journal of Nanotechnology (IF=3,65).

Abstract-book of the SPINTECH-NANO-2019 conference; (rights)
Special volume of the Beilstein J. Nanotechnolology 2020, 11, 1704–1706

3. Summer Schools

It was organized a summer school focused on *"S/F Hybrid Structures for Spintronics"* which took place in Chișinău (MD) on 27-30 September 2019 (right after the International Conference SPINTECH-NANO-2019).



SPINTECH Summer School evening session; (rights) SPINTECH Consortium meeting on 29.09.2019 – Prof.A.Sidorenko, Prof.A.Golubov and Prof.V.Krasnov discussed plan of the further activities

The first SPINTECH Summer School generated an international audience comprised of a comprehensive itinerary, including lectures from well-respected experts in the field. IEEN collaborators and PhD students gained new knowledge in the area of Spintronics during 3 days of the School. The event was hosted at D. GHITU IE and was attended by more than 30 young researchers as well as experienced researches and IIEN staff members. D. GHITU IE primarily presented their work in the field of thin films and vacuum technology including advanced technology and know-how (patented) in the techniques for the fabrication of functional nano-structures.

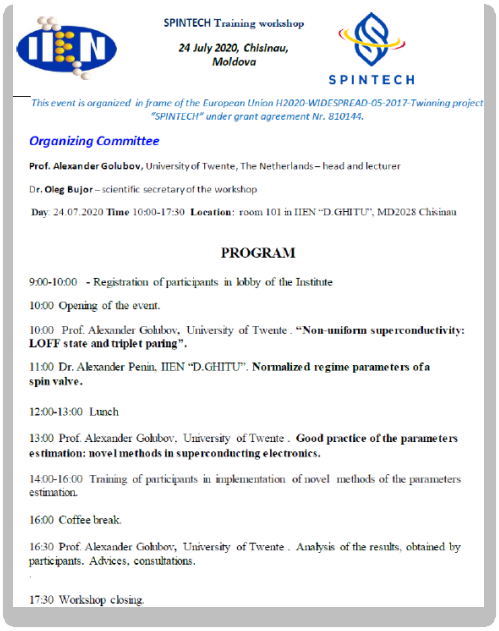
5.1. D2.2 – Year 2 Report on Training Workshops, Conferences and Summer Schools

5.2. Training Workshops

2 training workshops have been held during the second year of SPINTECH project: 1/ one in Chisinau on the 24 July 2020 focusing on “Novel methods of the parameters estimation of superconducting switching elements”; 2/ one in Twente on the 14 August 2020 focusing on “Advanced methods of nanostructures fabrication for Spintronics”.

Training Workshop at IIEN, Chisinau on the 24 July 2020

his training workshop focusing on “Novel methods of the parameters estimation of superconducting switching elements” was organised at D. GHITU IE in Moldova. Prof. Alexander Golubov from UTWENTE was the principal speaker and he presented with concrete examples the estimation of the main parameters of S/F functional nanostructures and spin valves. The event attracted a total of 21 participants from IIEN.



SPINTECH Training workshop

24 July 2020, Chisinau, Moldova

SPINTECH

This event is organized in frame of the European Union H2020-WIDESPREAD-05-2017-Twinning project "SPINTECH" under grant agreement Nr. 810144.

Organizing Committee

Prof. Alexander Golubov, University of Twente, The Netherlands – head and lecturer

Dr. **Oleg Bujor** – scientific secretary of the workshop

Day: 24.07.2020 **Time** 10:00-17:30 **Location**: room 101 in IIEN "D.GHITU", MD2028 Chisinau

PROGRAM

9:00-10:00 - Registration of participants in lobby of the Institute

10:00 Opening of the event.

10:00 Prof. Alexander Golubov, University of Twente . **"Non-uniform superconductivity: LOFF state and triplet paring".**

11:00 Dr. Alexander Penin, IIEN "D.GHITU". **Normalized regime parameters of a spin valve.**

12:00-13:00 Lunch

13:00 Prof. Alexander Golubov, University of Twente . **Good practice of the parameters estimation: novel methods in superconducting electronics.**

14:00-16:00 Training of participants in implementation of novel methods of the parameters estimation.

16:00 Coffee break.

16:30 Prof. Alexander Golubov, University of Twente . Analysis of the results, obtained by participants. Advices, consultations.

17:30 Workshop closing.

Program of the workshop

Training Workshop at UTWENTE on the 14 August 2020

European Commission

SPINTECH

MESA+ INSTITUTE FOR NANOTECHNOLOGY

Advanced methods of nanostructures fabrication for Spintronics

SPINTECH Training workshop

University of Twente, the Netherlands, 14 August 2020

(location: SQUID-laboratory of the MESA+)

This event is supported by the European Union H2020-WIDESPREAD-05-2017-Twinning project "SPINTECH" under grant agreement Nr. 810144.

Organizing committee:

Prof. Anatolie Sidorenko, "D.GHITU" IIEN, Moldova) director of the workshop

Prof. Alexander Golubov, University of Twente

Dr.Vladimir Kogan, University of Twente, scientific secretary of the workshop

http://nano.asm.md/ SPINTECH-workshop

The central goal of the SPINTECH training workshop- 2020 in Twente is to share the expertise and experience in developing of new principles and technological approaches for fabrication of superconducting electronics and spintronics devices, focussing on their novel implementations.

Program

9:00 Workshop opening – Prof. Alexander Golubov

9:15 Prof. Anatolie Sidorenko. Modified magnetron sputtering as powerful instrument of microelectronics.

10:30 Prof. Alexander Golubov. New design of superconducting circuits for spintronics.

11:30 Coffee break

12:00 Prof. Anatolie Sidorenko. Examples of the functional nanostructurs and spintronic devised fabricated by magnetron sputtering.

This training workshop focused on "Advanced methods of nanostructures fabrication for Spintronics". The two lecturers, Prof. A.Sidorenko (D. GHITU IE) and Prof. A.Golubov (UTWENTE) offered to the attendees detailed presentations of new principles and technological approaches for the fabrication of superconducting electronics and spintronics devices. The event took place in the SQUID Laboratory at Twente University attracted 11 participants including PhD students from MESA+.

Program of the training workshop

5.3. Conferences

5.4. Organisation of the conferences

Members of the SPINTECH consortium took part in several conferences during the second year of project in order to disseminate their research results on spintronics and to promote the SPINTECH project.

The SPNTECH project and the H2020 funding were acknowledged during all these events, which served also as promotional opportunities for the project. Conferences and seminars attended by members of the SPINTECH project and titles of their talks/presentations are listed below:

1. SPINTECH-International Conference "SPINTECH-NANO-2019"; 23-27 September 2019; Chisinau (Moldova).The central goal of the SPINTECH-NANO-2019 Conference is to bring together leading experts from 15 countries to share their expertise and experience in developing of new ideas and principles in nanoscience and nanotechnologies, focusing on their novel implementations.

2. Annual Meeting of the Israel Society for Medical and Biological Engineering (ISMBE); 25-26 February, 2020; Haifa (Israel), with the poster report presentation of A.Sidorenko:

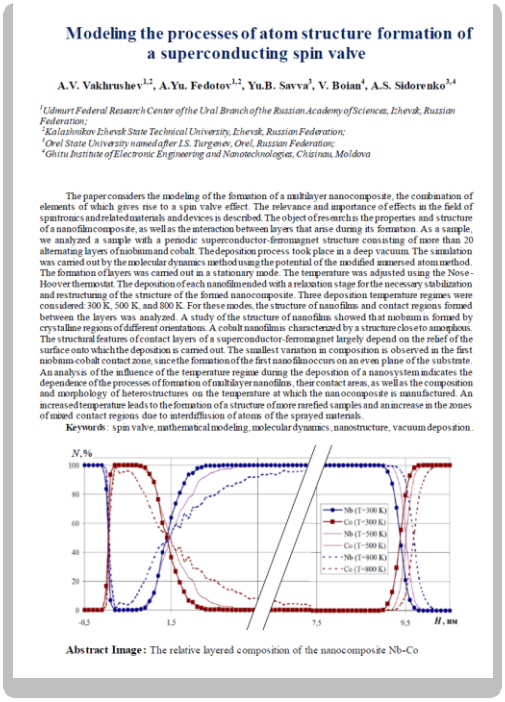
3. International Symposium "Nanophysics and Nanoelectronics", 10-13 March 2020, Nizhnii Novgorod, Russia - Invited plenary talk of prof. A. Sidorenko "Functional nanostructures superconductor-ferromagnet for superconducting spintronics" – presenting and disseminating results of the SPINTECH project, and with acknowledgements to the SPINTECH: Invited talk A.Sidorenko at Symposium "Nanophysics and Nanoelectronics" (D. GHITU IE)

4. Conference " March meeting of American Physical Society", 2-6 march 2020 Denver Colorado, USA – talk of Prof. V.Krasnov "Superconducting vortex-based memory cells"- presenting and disseminating results of the SPINTECH project.

5. XXIV International symposium on Nanophysics and Nanoelectronics, 10-13 march 2020, Nizhnii Novgorod, Russia.- invited talk of prof. V.Krasnov "Planar Josephson Junctions as Sensors for Scanning-Probe Microscopy "- presenting and disseminating results of the SPINTECH project:

Invited talk of V. Krasnov at symposium on Nanophysics and Nanoelectronics, Russia (SU)

5. Advisory board Meeting with consortium of SPINTECH project (Grant Agreement no: 810144) on 20 November 2020, Chisinau, Moldova.



Modeling the processes of atom structure formation of a superconducting spin valve

A.V. Vakhrushev[1,2], A.Yu. Fedotov[1,2], Yu.B. Savva[3], V. Boian[4], A.S. Sidorenko[3,4]

[1]Udmurt Federal Research Center of the Ural Branch of the Russian Academy of Sciences, Izhevsk, Russian Federation;
[2]Kalashnikov Izhevsk State Technical University, Izhevsk, Russian Federation;
[3]Orel State University named after I.S. Turgenev, Orel, Russian Federation;
[4]Ghitu Institute of Electronic Engineering and Nanotechnologies, Chisinau, Moldova

The paper considers the modeling of the formation of a multilayer nanocomposite, the combination of elements of which gives rise to a spin valve effect. The relevance and importance of effects in the field of spintronics and related materials and devices is described. The object of research is the properties and structure of a nanofilm composite, as well as the interaction between layers that arise during its formation. As a sample, we analyzed a sample with a periodic superconductor-ferromagnet structure consisting of more than 20 alternating layers of niobium and cobalt. The deposition process took place in a deep vacuum. The simulation was carried out by the molecular dynamics method using the potential of the modified immersed atom method. The formation of layers was carried out in a stationary mode. The temperature was adjusted using the Nose - Hoover thermostat. The deposition of each nanofilm ended with a relaxation stage for the necessary stabilization and restructuring of the structure of the formed nanocomposite. Three deposition temperature regimes were considered: 300 K, 500 K, and 800 K. For these modes, the structure of nanofilms and contact regions formed between the layers was analyzed. A study of the structure of nanofilms showed that niobium is formed by crystalline regions of different orientations. A cobalt nanofilm is characterized by a structure close to amorphous. The structural features of contact layers of a superconductor-ferromagnet largely depend on the relief of the surface onto which the deposition is carried out. The smallest variation in composition is observed in the first niobium-cobalt contact zone, since the formation of the first nanofilm occurs on an even plane of the substrate. An analysis of the influence of the temperature regime during the deposition of a nanosystem indicates the dependence of the processes of formation of multilayer nanofilms, their contact areas, as well as the composition and morphology of heterostructures on the temperature at which the nanocomposite is manufactured. An increased temperature leads to the formation of a structure of more rarefied samples and an increase in the zones of mixed contact regions due to interdiffusion of atoms of the sprayed materials.

Keywords: spin valve, mathematical modeling, molecular dynamics, nanostructure, vacuum deposition.

Abstract Image: The relative layered composition of the nanocomposite Nb-Co

A. *Sidorenko, lecture at Seminar IIEN, Chisinau (D. GHITU IE) on 25 Mai 2020*

6.1. D2.3 – Year 3 Report on Training Workshops, Conferences and Summer Schools

There is a brief report providing details about consortium members' participation in international conferences as well as the organisation of training workshops, conferences and summer schools during YEAR-3 (M25-M42) of SPINTECH. During this period, the project members have 6 summer/winter schools, organised 2 conferences and 7 seminars / training workshops.

6.2. Training Workshops

Five training workshops/seminars have been held during M25-M42: three in Chișinău (MD) during 22 March 2021, 19 April 2021 and 7-9 Sept 2021 plus two in Twente (NL) during 12-13 July 2021 and 10-13 November 2021.

Training workshop at IEEN on 22 March 2021

The SPINTECH project organised a training workshop on the "Modelling of Functional Nanostructures, their fabrication and investigation of the structure and morphology" at D.GHITU Institute in Moldova. The training was organized in a mixed form: the four (4) lecturers presented from the Institute while the 21 participants attended the lectures via Zoom conference mode to ensure safety in the COVID-19 era. Opening of the Training Workshop "Modelling of the Functional Nanostructures, their fabrication and investigation of the structure and morphology"; Prof. Anatolie Sidorenko (EIIN).

- "Modelling of the layered functional nanostructures superconductor/ferromagnet"; Prof. Alexander Golubov (UTWENTE).
- “Vacuum deposition of layered nanostructures"; Prof. Anatolie Sidorenko (EIIN).
- "Focused Ion Beam as a precise instrument for nanostructures fabrication"; Prof. Vladimir Krasnov (SU).
- "Effective management of the European project in case of COVID-19 pandemic restrictions"; Dr. Oleg Bujor (EIIN).

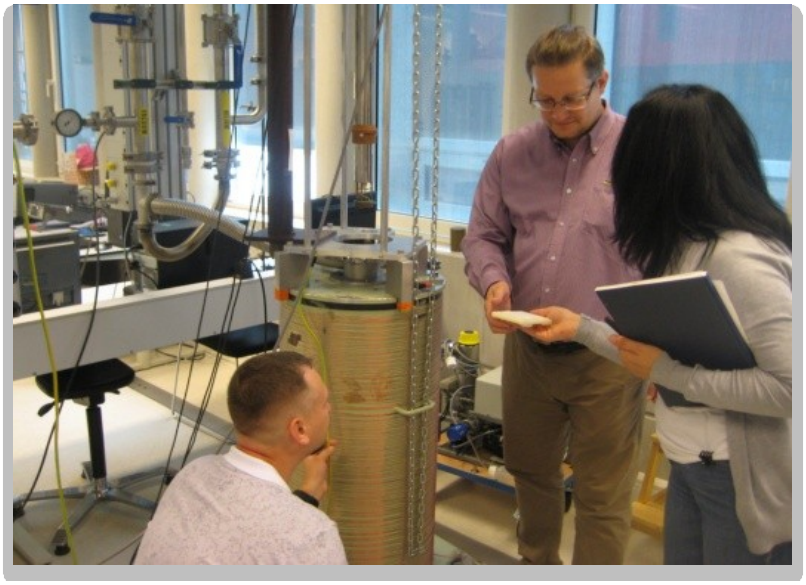
Seminar at IEEN on 19 April 2021

The SPINTECH project and the Association of Physicists of Moldova (SFM) organised a seminar in Chișinău (Moldova). The aim of the seminar was to discuss a new report recently published at national level: “Quo Vadis? Ethics of Scientific Research: Artificial Neural Networks”. An artificial neural network (ANN) or a brain-like computer with a non-von Neumann architecture surpasses the speed of neurons in the human brain (e.g. a biological neural network in terms of switching speed). For a number of tasks, the ANN will become an extremely useful tool, such as air traffic control. Tragic mistakes of air controllers are known due to their fatigue and overload and ANN does not know such fatigue. It can accurately manage air flows for days and months without interruption. But other applications of artificial intelligence systems might also benefit from ANN including virusological genetic engineering or militarization of space. 70 years ago, the American science fiction writer Isaac Asimov formulated three ethical laws of robotics - a code of rules for robots. Already at that time, he identified problems we are facing nowadays and they are becoming more and more urgent - as the capabilities of neural networks and artificial intelligence systems are developing. In this seminar, we will get acquainted with the basic principles of the construction and functioning of the first artificial neural network: the Perceptron.

Training workshop at UTWENTE during 12-13 July 2021

The SPINTECH project organised a Training Workshop on “Advanced methods of nanostructures characterization” in Twente University on the 12-13 July 2021. The 2-day event consisted in a mix of laboratory visits, presentation and use of equipment and training lectures focusing on topics relevant to SPINTECH project. During the event, the 22 participants raised their knowledge on three advanced methods, namely:

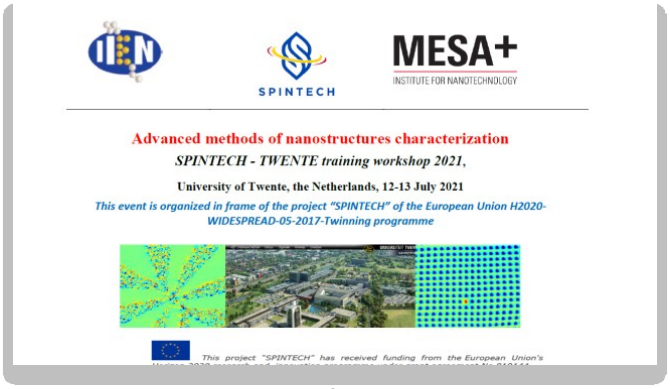
- XRD diffractometry of nano-sized samples;
- Low –temperature measurements and advanced methods of brain-like circuits characterization in the BRAINS Centre;
- SQUID-microscope installation and methods of magnetometry of nanostructures;



Training on SQUID-microscope (links); Lecture of Prof.Wilfrid van der Wiel in Brains Centre TWENTE (rights) on 13th July 2021

Visit of the centre of materials and structures characterization (DANNALAB) - 12 July 2021.

The director of DANNALB, Dr. Vladimir Kogan presented XRD installations and laboratory equipment, while explaining the methods used for materials characterization, investigation of various materials, nanostructures, microelectronic elements, as well as multifunctional diffractometer "X'Pert -PRO" of the PANalytical company.



Participants received a tailored training on the diffractometer and the XRD equipment "X'Pert -PRO" of the PANalytical company - X-ray diffractometer of high resolution, connected with the internet to provide investigation of samples in the remote mode - automated measurements of the XRD- characteristics of layered nanostructures. In particular, participants learned advanced methods of spintronic-samples characterization.

Visit of the Magnetometry Lab at Twente University - 13 July 2021
Participants have learned methods of magnetic properties of nano-layered structures investigation in the high-sensitive SQUID-microscope and have done measurements of magnetic state of spintronic nanostructures Nb/Co, assisted by Prof. Alexander Golubov using the SQUID-microscope installation.

Visit of the "BRAINS Centre for Brain-Inspired Nano Systems" - 13 July 2021
The Director of the BRAINS Centre, Prof. Wilfred van der Wiel, gave a lecture on the design and capacity of the brain-like circuits, elaborated in the Centre. Participants also have the chance to learn about methods of low-temperature experiments in the BRAINS Centre, elaborated there for investigation of the brain-like circuits.

Training workshop at IEEN during 7-9 Sept 2021
The SPINTECH project organised a training workshop on "Artificial Neuronal Networks: from nanofabrication to deep-learning" in Chișinău during 7-9 Sept 2021. The workshop was the subject of an AVA TV programme, which included an interview with esteemed workshop participant Prof. Isaak Bersuker of the University of Texas at Austin.
Comprehensive details regarding the workshop are provided below.
Organizing committee
Prof. Anatolie Sidorenko, IEEN Chișinău, Moldova
Prof. Alexander Golubov, Uni-TWENTE, Enschede, Netherlands
Prof. Vladimir Krasnov, Uni-Stockholm, Sweden
PROGRAM
Day 1, 07.09.2021, Tuesday
12:00-18:00 Arrival of participants, accommodation in the Hotel Radisson Blu Leogrand Hotel "KLASSIK" ("Hotel Club Service", str. Mihail Kogalniceanu 6, MD 2001, Chișinău, E-mail: info@klassikhotel.md, tel. 022 838 388)
Day 2, 08.09.2021, Wednesday
Location: Conference Hall of the D.GHITU Institute of Electronic Engineering and Nanotechnologies, str. Academiei 3/3 Chișinău, Moldova, room 101, tel.+37322 - 737092
9:30 Opening of the Meeting - Coordinator of the SPINTECH project Prof. Anatolie Sidorenko
10:00 Prof. Igor Lukyanchuk, University of Amien, France, coordinator of the "MELON" project. Ferroic nanomaterials for Artificial Neural Network.
11:00 Prof. Isaak Bersuker, University of Texas, USA. Jahn−Teller and Pseudo-Jahn−Teller Effects: From Particular Features to General Tools in Exploring Molecular and Solid State Properties.
12:00 Lunch break
14:00 Prof. Wilfred van der Wiel, Uni-TWENTE, Director of BRAINS Center for Brain-Inspired Nano Systems. Artificial neural network – "Material learning".

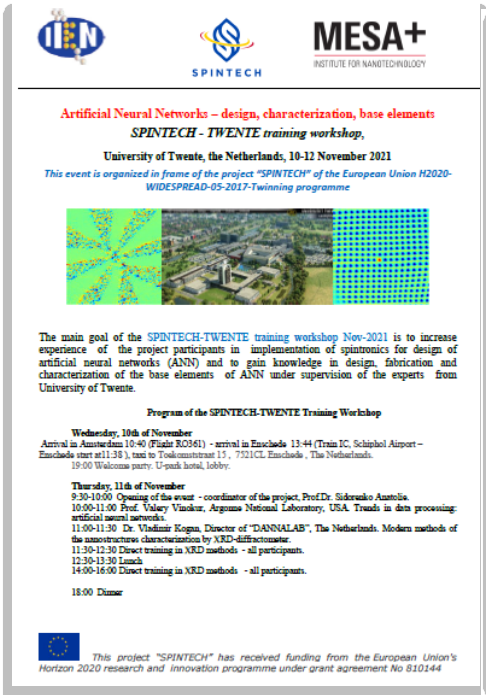
15:00 Prof. Alexander Vakhrushev, Head of Department of Nanotechnology and Microsystems, Izhevsk State Technical University, Izhevsk, Russia. Mathematical modeling of nanofabrication.
16:00 Prof. Nikolai Klenov + Prof. Igor Soloviev. Moscow State University, Russia. Base elements of ANN – artificial neuron and synapse.
17:00-18:00 Press conference
Day 3, 09.09.2021, Thursday
Location: conference hall of the Hotel Radisson Blu Leogrand Hotel "KLASSIK" ("Hotel Club Service", str. Mihail Kogalniceanu 26, MD 2001, Chișinău, E-mail: info@klassikhotel.md, tel. 022 838 388)
9:30 Prof. Igor Lukyanchuk, coordonator of the EU project MELON, Amien, France. Administration of the EU project.
10:00 Dr. Oleg Bujor. National Point of Moldova of the HORIZON-2020 program. Financial management and audit of the HORIZON-2020 projects.
11:00-12:00 Round-table discussion with members of the Advisory Board of the SPINTECH Project.
12:00-13:00 Lunch break
14:00-16:00 External session: out-reach activity of the SPINTECH project, visit of the Theoretical Lycei N.V.Gogol, Chișinău - meeting members of the SPINTECH project with schoolchildren, teachers and director – to inform them about Artificial Intellect, Neural Networks, about scientific work and international scientific collaboration. (Str. Alexei Şciusev 90, Chișinău 2012,Tel. 022 238382)
17:00 Television (Moldova-1) - interview with invited lecturers of the workshop.

Training workshop at UTWENTE during 10-13 Nov 2021

The main goal of the three-day workshop in Twente was to increase the knowledge of the 30 participants (12 of them came personally from Moldova) in the implementation of spintronics for the design of artificial neural networks (ANN) and to gain knowledge in the design, fabrication and characterization of base elements of ANN under the supervision of the University of Twente's experts. The workshop's programme (shown below) included lectures of experts, in particular presentation of Prof. Sidorenko on hybrid nanostructures for spintronics and qubits, prof. Valerii Vinokur "Topological nature of high-temperature superconductivity", lecture of Dr. Vladimir Kogan about modern methods of high-resolution diffarctometry, Prof. Alexander Brinkman about SQUID-microscopy of superconductors as well as presentation of the research directions of the BRAINS Centre for Brain Inspired Nano Systems by the centre's director, Prof.dr.ir. Wilfred G. van der Wiel.

On the Photo: (left) Opening of the Workshop on 11th November; (right) Lecture of prof. Valerii Vinokur "Topological nature of high-temperature superconductivity" on 12th November.

Program of the workshop:



Artificial Neural Networks – design, characterization, base elements

SPINTECH - TWENTE training workshop,

University of Twente, the Netherlands, 10-12 November 2021

This event is organized in frame of the project "SPINTECH" of the European Union H2020-WIDESPREAD-05-2017-Twinning programme

The main goal of the SPINTECH-TWENTE training workshop Nov-2021 is to increase experience of the project participants in implementation of spintronics for design of artificial neural networks (ANN) and to gain knowledge in design, fabrication and characterization of the base elements of ANN under supervision of the experts from University of Twente.

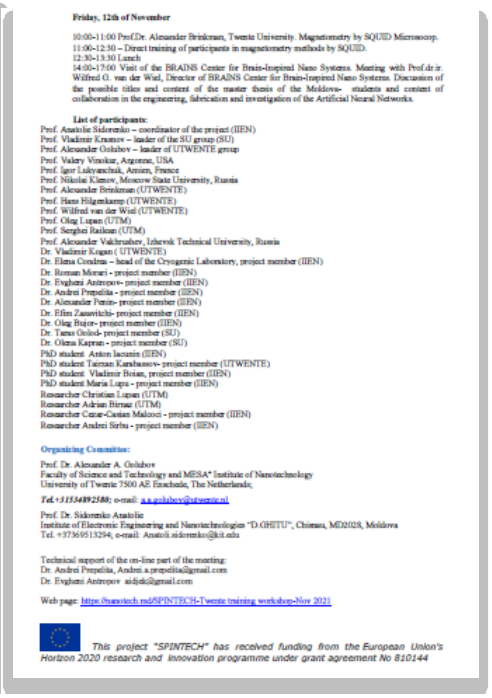
Program of the SPINTECH-TWENTE Training Workshop

Wednesday, 10th of November
Arrival in Amsterdam 10:40 (Flight KO361) - arrival in Enschede 13:44 (Train IC, Schiphol Airport – Enschede start at11:38), taxi to Toskamstraat 15 , 7521CL Enschede , The Netherlands.
19:00 Welcome party. U-park hotel, lobby.

Thursday, 11th of November
9:30-10:00 Opening of the event - coordinator of the project, Prof.Dr. Sidorenko Anatolie.
10:00-11:00 Prof. Valery Vinokur, Argonne National Laboratory, USA. Trends in data processing: artificial neural networks.
11:00-11:30 Dr. Vladimir Kogan, Director of "DANNALAB", The Netherlands. Modern methods of the nanostructures characterization by XRD-diffractometer.
11:30-12:30 Direct training in XRD methods - all participants.
12:30-13:30 Lunch
14:00-16:00 Direct training in XRD methods - all participants.

18:00 Dinner

This project "SPINTECH" has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 810144



Friday, 12th of November

10:00-11:00 Prof.Dr. Alexander Brinkman, Twente University. Magnetometry by SQUID Microscop.
11:00-12:30 – Direct training of participants in magnetometry methods by SQUID.
12:30-13:30 Lunch
14:00-17:00 Visit of the BRAINS Center for Brain-Inspired Nano Systems. Meeting with Prof.dr.ir. Wilfred G. van der Wiel, Director of BRAINS Center for Brain-Inspired Nano Systems. Discussion of the possible titles and content of the master thesis of the Moldova- students and content of collaboration in the engineering, fabrication and investigation of the Artificial Neural Networks.

List of participants:
Prof. Anatolie Sidorenko – coordinator of the project (IIEN)
Prof. Vladimir Krasnov – leader of the SU group (SU)
Prof. Alexander Golubov – leader of UTWENTE group
Prof. Valery Vinokur, Argonne, USA
Prof. Igor Lukyanchuk, Amien, France
Prof. Nikolai Klenov, Moscow State University, Russia
Prof. Alexander Brinkman (UTWENTE)
Prof. Hans Hilgenkamp (UTWENTE)
Prof. Wilfred van der Wiel (UTWENTE)
Prof. Oleg Lupan (UTM)
Prof. Serghei Railean (UTM)
Prof. Alexander Vakhrushev, Izhevsk Technical University, Russia
Dr. Vladimir Kogan (UTWENTE)
Dr. Elena Condrea – head of the Cryogenic Laboratory, project member (IIEN)
Dr. Roman Morari - project member (IIEN)
Dr. Evghenii Astropov- project member (IIEN)
Dr. Andrei Prepelita - project member (IIEN)
Dr. Alexandr Perois- project member (IIEN)
Dr. Efim Zasavitchi- project member (IIEN)
Dr. Oleg Bajor- project member (IIEN)
Dr. Taras Orlova- project member (SU)
Dr. Olena Kapran - project member (SU)
PhD student Anton Iacumin (IIEN)
PhD student Tazrian Karabasov- project member (UTWENTE)
PhD student Vladimir Boian, project member (IIEN)
PhD student Maria Lupa - project member (IIEN)
Researcher Christian Lupan (UTM)
Researcher Adrian Birsan (UTM)
Researcher Cezar-Casian Malaicu - project member (IIEN)
Researcher Andrei Sirbu - project member (IIEN)

Organizing Committee:
Prof. Dr. Alexander A. Golubov
Faculty of Science and Technology and MESA+ Institute of Nanotechnology
University of Twente 7500 AE Enschede, The Netherlands,
Tel.+31534892588; e-mail: a.a.golubov@utwente.nl

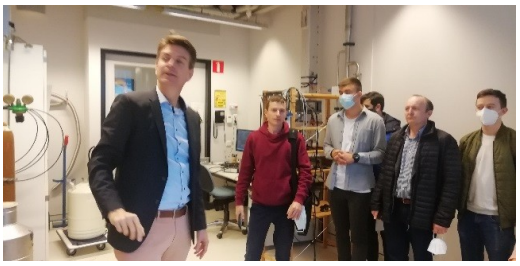
Prof. Dr. Sidorenko Anatolie
Institute of Electronic Engineering and Nanotechnologies "D.GHITU", Chisinau, MD2028, Moldova
Tel. +37369513294; e-mail: Anatoli.sidorenko@kit.edu

Technical support of the on-line part of the meeting:
Dr. Andrei Prepelita, Andrei.a.prepelita@gmail.com
Dr. Evghenii Astropov asftdt@gmail.com

Web page: https://nanotech.md/SPINTECH-Twente training workshop-Nov 2021

This project "SPINTECH" has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 810144

Workshop was organized in the mixed format: 12 participants from Moldova were presented in the meeting room, 18 participants took part on-line. After listening of the lectures it was organised direct training of the participants in the laboratories (XRD, SQUID, BRAINS Centre).




On photo: (left) UTWENTE Brains centre's director, Prof.dr.ir. Wilfred G. van der Wiel presents directions of research; (right) group of researchers from IEEN, Moldova by direct training in the BRAINS Centre

Training workshop at D.GHITU IEEN on 20 January 2022

At the one-day training workshop "Spintronics highlights: Functional nanostructures fabrication&characterization" 14 participants, IEEN collaborators listened to lectures about the newest methods of fabrication of functional nanostructures, their treatment with advanced milling processes and characterization with high resolution diffractometry and polarized neutron spectrometry and than they had the practical training on the vacuum installation for magnetron sputtering "Leybold-Z400". Location of the training: Cryogenic laboratory of the D.GHITU Institute of Electronic Engineering and Nanotechnologies, str. Academiei 3/3 Chisinau, Moldova, the fulfilled program of the training was the following:

20 January 2022, Chişinău, Moldova

Training "Spintronics highlights: Functional nanostructures fabrication&characterization"

(Location: Cryogenic laboratory of the D.GHITU Institute of Electronic Engineering and Nanotechnologies, str. Academiei 3/3 Chisinau, Moldova, tel.+37322 -737072)

9:00-9:40 Prof. Anatolie Sidorenko, IEEN Chisinau, Moldova. Artificial Superconducting Synapses and Neurons based on layered hybrid S/F structures.
9:40-10:00 Dr. Taras Golod. Stockholm University, Sweden. Nanofabrication of Josephson contacts using FIB process.
10:00-10:30 Prof. Vladimir Krasnov, Stockholm University, Sweden. Crossover phenomena in SFS Josephson junctions.
10:30-11:00 Coffee break
11:30-12:00 Dr. Vladimir Fedorov. IEEN Chisinau, Moldova. Vacuum deposition of layered heterostructures.
12:00-12:30 Dr. Vladimir Kogan, DANNALB, Enschede, The Netherlands. Nanostructures characterization by precise XRD techniques.
12:30-14:00 Lunch break
14:00- 17:00 Training of all participants in the Cryogenic laboratory on "Z-400 Leybold" magnetron sputtering installation.
19:00 Dinner

On photo: some of lecturers of the winter school (Prof.A.Sidorenko, Prof.V.Ryazanov) and some of school-participants (PhD student V.Boian and Dr. R. Morari) in Cryogenic laboratory by training on Leybold-Z400

SPINTECH Training workshop at IEEN on 24-25 February 2022

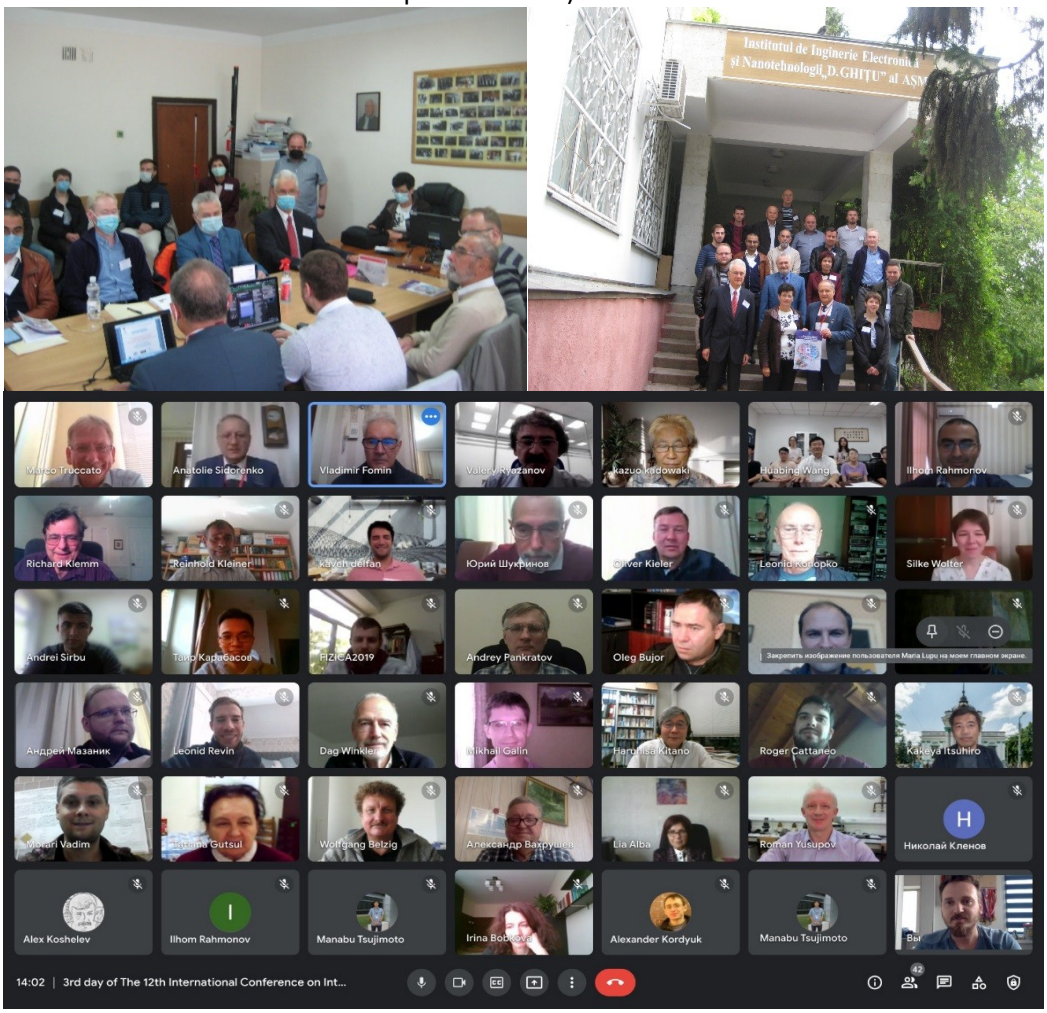
During two days training workshop"Artificial Synapses for Spintronics" *24-25 February 2022* participants gained knowledge in the newest direction Spintronics – artificial neurons and artificial synapses, their design and engineering. Workshop was organised in the mixed format – 18 participants off-line and 2 They have listened lectures of Prof. Anatolie Sidorenko (IEEN Chisinau, Moldova): "Artificial Superconducting Synapses based on superconductor-ferromagnet heterostructures fundamentals and fabrication", lecture of Dr. Igor Golovchanckiy (Moscow Institute of Physics and Technology MIPT, Dolgoprudny): "Ferromagnet/Superconductor Hybrid Magnonic Metamaterials" and lecture of Prof. Alexander Golubov, (University of Twente) "Basics of superconducting spintronics".

6.3. Conferences

Conferences and seminars attended by members of the SPINTECH project and titles of talks/presentations are reported below for the period M25-M42. Funding from H2020 was acknowledged during all events, which served also as promotional opportunities for the project.

The SPINTECH partners organised the international conference 12th International Conference on Intrinsic Effects and Horizons of Superconducting Spintronics during 22-25 September 2021 in Chișinău, Moldova. Its aim was to bring together leading experts from 16 countries: Japan, USA, Germany, France, Russia, Ukraine, Moldova, Romania, Netherlands, Sweden, Italy, UK, Spain, China, South Korea to share their expertise and

experience in developing of new ideas and principles, novel technologies and their implementations on frontiers of superconducting electronics and spintronics (opening of the conference is shown in the photos below).



Photos and Screen-shot during the opening of the conference

A major news feature about the conference - the interview given by Prof. A.Sidorenko was published in the newspaper Moldavskie Vedomosty (Moldovan News).

Conference venue*:*

Institute of Electronic Engineering and Nanotechnologies, str.Academiei 3/3, Chisinau, MD2028 Moldova, and hotel KLASSIK ("Hotel Club Service", str. Kogalniceanu nr. 6, MD-2001, Chisinau, Moldova).

Organizing Committee

Prof. Anatolie Sidorenko, IEEN Chisinau, Moldova

Prof. Alexander Golubov, University of Twente, The Netherlands

Prof. Vladimir Krasnov, University of Stockholm, Sweden

Local Organizing Committee:
Director of the conference Prof. Sidorenko Anatolie
"D.GHITU" Institute of Electronic Engineering and Nanotechnologies, Academiei str.3/3, MD2028, Chisianu,Moldova; Phone/Fax/E-mail: +37322-737092/ +37322-727088/ anatoli.sidorenko@kit.edu
Scientific secretary of the conference: Dr. Antropov Evgheni, IEEN Chisinau, Moldova, e-mail: aidjek@gmail.com; Viber: +37379757615
Administrator of the conference: Dr. Bujor Oleg, IEEN Chisinau, Moldova, e-mail: bujor.oleg@gmail.com
Additional information and program of the Conference are placed on the web page: https://nanotech.md/en/page/89/spintech-nano-2021

In the special volume of the Beilstein Journal of Nanotechnology (IF-3,65) the best reports was presented (published in 2022).
1. Prof. A.Sidorenko was Co-organiser of two on-line events on 30th September 2021:
- **1st LeNS International Seminar, Jakarta, Indonesia (see Photo below)**
- **The 1st Lekantara Annual Conference on Natural Science and Environment, Jakarta, Indonesia, 30th September 2021.**

Materials of the Conference and reports are available on the page: https://www.youtube.com/watch?v=SKvnuXgy6O8

Rundown

1st Lekantara Annual Conference on Natural Science and Environment (LeNS)

Here is the schedule for Saturday, October 30, 2021 from 12.30 (Open Gate) to 04.00 pm (GMT+7)

No.	Time (pm)	Agenda	PIC
1.	12.30-01.00	Open gate Zoom Meeting	Operator
2.	01.00-01.20	A. Opening by Moderator B. Indonesia's National Anthem (video) Welcoming remarks by CEO of Lekantara	Operator Moderator (Amalia Permata Rizky, M.Kom.)
3.	01.20-01.50	Keynote Speech – Dr. Ir. Suswono	Operator
4	01.50-02.20	Keynote Speech – Prof. Sidorenko Anatolie	Operator
5	02.20-02.50	Keynote Speech – Dr. Melati Ferianita Fachrul, MS.	Operator
6	02.50-03.20	Keynote Speech – Sergey Plygun, Ph.D	Operator
6	03.20-03.50	Panel Discussion	Operator


LEKANTARA

CERTIFICATE

Nomor: 177/LAN/CNF/I.01/04/X/2021

This is to certify that

Prof. Dr. Sidorenko Anatolie

In recognition of valuable contribution as

Keynote Speaker

In the 1st Lekantara Annual Conference on Natural Science and Environment (LeNS) held on **October 30th 2021**, via Zoom Cloud Meeting

Dean of Faculty of Landscape Architecture & Environmental, Universitas Trisakti

Dr. Melati Ferianita Fachrul, MS.

CEO of Lekantara

Aulia Luqman Aziz

2. Hybrid nanostructures superconductor ferromagnet for superconducting spintronics. A S Sidorenko, report at international conference "Functional Nanomaterials and High-Purity Materials", Suzadli, 5-9 October 2020. Proceedings, p.12.

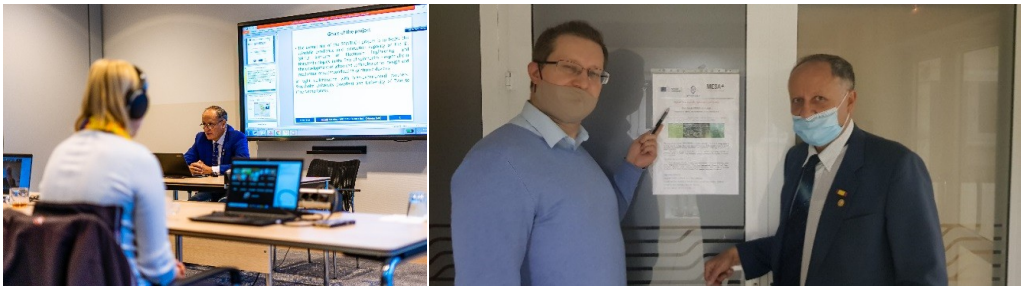
3. Crossover in superconductor/ferromagnet/superconductor junctions with Ni-based ferromagnets. Anatoli Sidorenko, invited talk at „3nd Virtual Congress on Materials Science and Engineering. Materials Info 2021", 27 September 2021, Switzerland. Procedings of the conference, p.34.
4. Functional nanostructures with complex topology. Sidorenko Anatolie, invited talk at International Colloquium "Topology- and Geometry-Controlled Functionalization of Nanostructured Metamaterials", August 24, 2020, Madrid.
5. Layered nanostructures for superconducting spintronics. Anatolie Sidorenko, invited talk at 7th International Conference on Superconductivity and Magnetism – "ICSM-2021", 21st -27th October 2021, Bodrum, Turkey.
6. ADVANCED TECHNOLOGY of ACTIVE INFLUENCE on HAIL PROCESSES for SECURITY of FOOD PRODUCTION. Anatolie Sidorenko, Plenary Talk at 1st Lekantara Annual Conference on Natural Science and Environment (LeNS) on 30 September 2021, Jakarta, Indonesia.
7. Nanostructures Superconductor/Ferromagnet for Superconducting Spintronics. *Anatolie Sidorenko, plenary talk at* 12th International Conference on Intrinsic Effects and Horizons of Superconducting Spintronics during 22-25 September 2021 in Chișinău, Moldova.

6.3. Summer and Winter Schools

Six summer/winter schools have been held during M25-M42: two in Twente (NL) during 2-3 October 2020 (focused on Hybrid Structures for Spintronics and Qubits) and 10-12 February 2022, focused on "Functional nanostructures – modelling, design, characterization", two in Stockholm (SE) during 27-28 May 2021 (focused on Brain-like Artificial Neural Networks) and 3-4 February 2022 (focused on Superconducting Spintronic's Alternative) and finally two in Chișinău (MD) during 10-11 December 2021 (focused on Non-conventional Superconductivity Implementation in Spintronics), 21-22 January 2022 (focused on Spintronics highlights: hybrid nanostructures), details are presented in 3.1-3.6 and in Annexes 2-7.

Summer school at UTWENTE during 2-3 October 2020

The SPINTECH Summer School "Hybrid Structures for Spintronics and Qubits" was organised in collaboration with by the partner UTWENTE in the U-Park hotel and it's facilities in the university campus during 2-3 October 2020. Due to the current Covid situation and restrictions, the event was extended to online participants including the international speakers in order to ensure a high quality of presentations despite the travel restrictions. In total, the event attracted a total of 32 participants. Excellent lectures about highlights of spintronics were presented by leading experts all over the world – from Japan, USA, Germany, France and Netherlands.



Opening of the Summer School on 02.10.2021

A video about the summer school has been published on the project website, access is available here (https://www.h2020-spintech.eu/news-20102020.html).

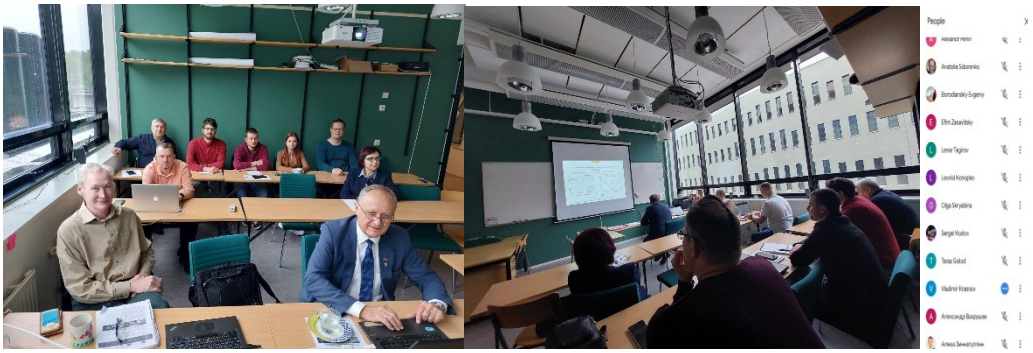
Summer school at SU during 27-28 May 2021

The SPINTECH project organised a summer school “Brain-like Artificial Neural Network: Superconducting Spintronic’s Alternative” the 27-28 of May 2021 at the University of Stockholm “Alba Nova”. During the two-day school, a total of 9 lectures were presented to the audience consisting in 44 participants: 13 participants attending the event in Stockholm and 31 registered online using Google Meet applications

By listening of the excellent lectures of Prof. Kavokin and Prof. Kusmartsev from Great Britain, presented the revolutionary new architecture of the non-von Neumann computers, brain-like designed artificial neural networks. Participants of the school gained deep knowledge in the field of artificial intelligence, they learned from lectures of Prof. Golubov, Prof. Sidorenko, Prof. Krasnov, Prof,Vakhrushev and Prof. Klenov presented fundamental principles of operation of the superconducting base elements, artificial neurons and artificial synapses and a possible design of their interconnection and operation of the elements in ANN.

Following the lectures, a round-table discussion was organised between Prof. Lukyanchuk, Prof. Soloviev, Prof. Krasnov, Prof. Sidorenko, Prof. Kusmartsev, Prof. Kavokin and Prof. Golubov who expressed their opinion about the most promising solutions in the novel area of research and engineering - non-von Neumann computers on the base of artificial neural network (ANN).

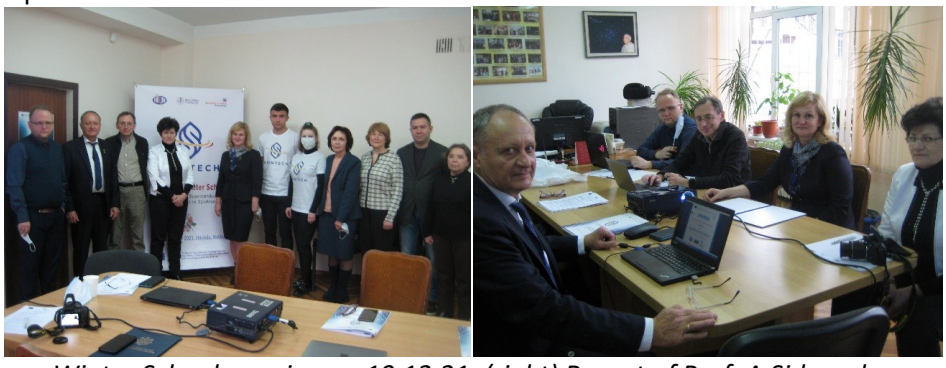
It was proposed by Prof. Krasnov to continue the discussions on the optimal ANN configurations and the possible collaboration between partners in that field. This topic of mutual interest and related joint opportunities will be further discussed in the forthcoming SPINTECH international conference "12th International Conference on Intrinsic Josephson Effect and Horizons of Superconducting Spintronics" in Chișinău (Moldova) on the 22-25 September 2021.



Participants of the Summer School in Stockholm University and in on line form

Winter school at IEEN during 10-11 December 2021

A two-days Winter School dedicated to "Non-conventional Superconductivity Implementation in Spintronics" was organised in D. Ghitu Institute of Electronic Engineering and Nanotechnologies in the frame of the SPINTECH project. The event was in a mixed format – 19 participants were physically present and 18 others participated online.



Winter School opening on 10.12.21; (right) Report of Prof. A.Sidorenko

On the first day of the Winter School, the following presentations and lectures were made among others:

- Prof. Anatolie Sidorenko presented the goals and main results achieved so far in the SPINTECH project.
- Prof. Igor Lukyanchuk, Amien, France, presented the EU project "MELON", being it's coordinator and announced the new concept – CLUSTERING, the new promising form of networking with EU projects.
- Prof. Alexander Kordyuk, Kiev, Ukraine, presented superconducting spintronics base elements.
- Prof. Valery Vinokur, Chicago, USA, held a 1,5 hour lecture about the nature of High-Tc superconductivity and the concept of magnetic monopoles.

Very interesting and lengthy discussions were stimulated as a result of the lectures.
On the second day of the Winter School, an Advisory Board meeting of the SPINTECH project was organised involving Prof. Anatolie Sidorenko (project coordinator), Prof. Elena Achimova (Institute of Applied Physics, Chisinau), Prof. Denis Nica (State University of Moldova), Prof. Peter Bogatenkov (RENAM company, Chisinau), Prof. Artur Buzdugan and Dr. Sergei Railean (Technical University of Moldova), were discussed the prospects for the SPINTECH project's results (on the Photo below).

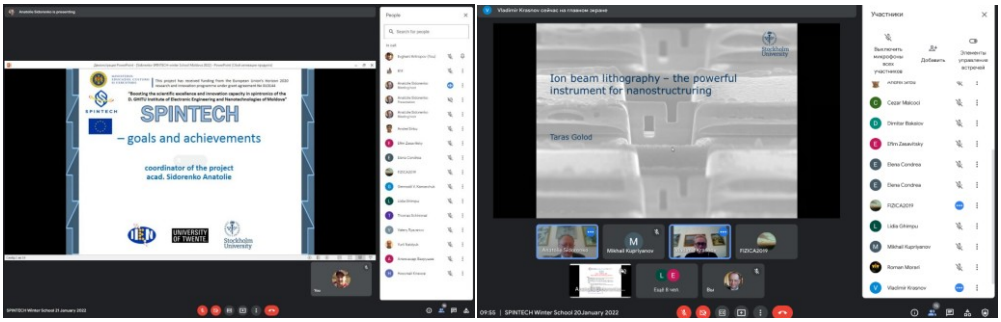
Advisory board meeting of the SPINTECH project on 11.12.2021

A slideshow about the winter school has been published on the project website. (https://www.h2020-spintech.eu/news-16122021.html).

Winter school at IEEN during 21-22 January 2022

The additional training and winter school ”Spintronics highlights: hybrid nanostructures ” was dedicated to hybrid nanostructures fabrication and characterisation, was held during 20-22 January. Notably, director of the Institute for Low Temperature Physics National Academy of Sciences, of Ukraine, the world

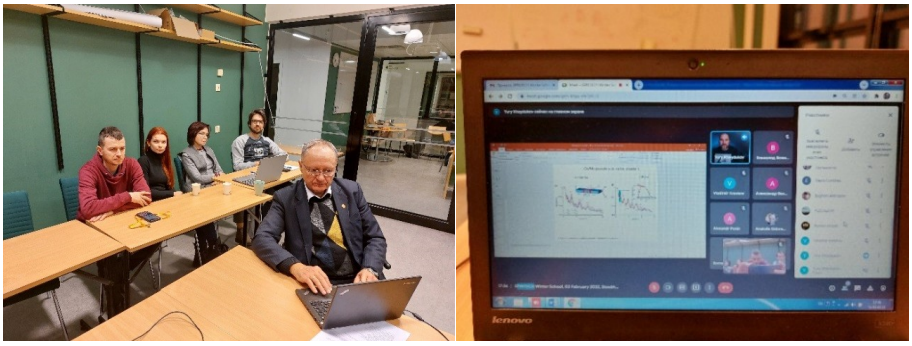
recognised leading expert in point-contact spectroscopy academician Prof. Yurii Naydiuk and head of the *Department of Spectroscopy of Molecular Systems and Nanostructured Materials the same institute* Prof. Gennadii Kamarchuk were invited as speakers from Kharkiv, Ukraine, and gave lectures about the fundamentals of functional hybrid nanostructures and about new phenomena detected with the powerful method of point-contact spectroscope. It led to increasing of the scientific level of IEEN collaborators, listened that excellent lectures and in general, led to achievement of the goals of the SPINTECH broject – boosting of it's excellence. A hybrid format was adopted for that winter school with 15 participants in person and 18 participants online, as shown in photo below, were the screen-shots during the lectures given by Prof. Anatoli Sidorenko and Dr. Taras Golod are given. The full text of the given lectures is published in the book Annex.



Winter School at SU during 03-04 February 2022

The additional winter school "Superconducting Spintronic's Alternative" was organised together with prof. Vladimir Krasnov and with assistance of dr. E.Condrea and dr. L.Bujor on 03-04 February 2022 in Stockholm. A hybrid format was adopted for that winter school with 12 participants in person and 18 participants online.

Prof. A.Sidorenko gave two lectures "SPINTECH project – goals, achievements and networking" on 03.02.2022, and "Smart methods of nanostructures fabrication for spintronics" on 04.02.2022. (in the photo below). From the lecture "Polarized Neutron Reflectometry as a powerful tool for layered hybrid nanostructures investigation", given by Dr. Yuri Khaydukov. (Max-Planck Institute Stuttgart, Germany) participants gained knowledge about very informative direct method of investigation of the spin configurations in the magnetic materials, what is important for development of the superconducting spintronics. Lecture "In-situ analysis of magnetic states in nanostructured S/F heterostructures" of Prof. Vladimir Krasnov, (Stockholm University, Sweden) extended knowledge of the participants about another smart and sensitive method of magnetic states investigation – "FORC", developed in Stockholm – "First-Order-Reversal-Curves" (FORC) analysis. FORC is a powerful tool for *in situ* characterization of magnetic states in complex ferromagnetic structures and learning of that method was very useful for IEEN collaborators, participated in that winter school.



In Photo: Lecture of Prof. A.Sidorenko on 04.02.2022 and participants of the Winter School in the meeting room of SU, and participants on-line (right, in screen-shot)

Winter school at UTWENTE during 10-12 February 2022

For the winter school "Functional nanostructures – modelling, design, characterization"

held in Twente during 10-12 February 2022, the research focus was on modelling, design, characterization of functional nanostructures. The participants learned smart methods of nanostructured samples characterization and listened to the following lectures:

- Dr. Joachim Woitok ("DANNALAB", Enshede, The Netherlands): "Modern methods of the nanostructures characterization by XRD-diffractometer"
- Dr.Thomas Koch (Analytical Intelligence Research Services of KRONOS INT. Inc., Leverkusen, Germany): "Advanced X-Ray Based Methods for Powder Characterisations"
- Dr. Igor Makhotkin (Thin Films Fabrication Center of the Unversity of Twente.). Magnetron sputtering of multilayered nanostructures with high periodicity.

Training was provided on nanostructure characterisation in the Thin Films Fabrication Center of the Unversity of Twente under supervision of Dr. I.Makhotkin.

7.1. D3.4 – Outreach Activities

Executive Summary

During this period, the project members have organised 2 SPINTECH conferences in Chisinau, Moldova, 6 summer/winter schools (2 in Moldova, 2 in Sweden, 2 in Netherlands) and 10 training workshops.

The project website (www.h2020-spintech.eu) has been available since early September 2018. The deliverable D3.2 "Project Website" was submitted on 31/12/2018. The website has been regularly updated with materials and news since its creation. Already by the end of the Period 1, the website has received 458 views.

In addition, a Research Gate project page has also been set up for SPINTECH activities, which is available at: https://www.researchgate.net/project/SPINTECH-superconducting-spintronics.

The project SPINTECH also has a Twitter account with the handle: @H2020_SPINTECH.

With the aim of information of the wide audience – scientists and general public, we have done in January-February 2022 the film about project SPINTECH, it's goals, development of the new science/engineering area – Spintronics, about scientific results and out-reach activities achieved within the project implementation and about further prospects. The film is available using the link:
https://disk.yandex.ru/i/TCQV-9duwyOxYA

8.1. Press Conferences

4 press conferences have been held during the whole project: A on 21.09.2018, B on 05.03.2019, C on 24.09.2019 and D on 08.09.2021.

Press conference A on 21.09.2018

Kick-off meeting of the SPINTECH project took place in the Ministry of Education, Culture and Research (MECC) of Moldova 21 September 2018. Minister Dr. Monica Babuc opened the meeting and mentioned exceptional importance of the EU project for Moldova and for integration of the Republic of Moldova in the European space:

Minister MECC, Dr. Monica Babuc and State Secretary Dr. Elena Belei and coordinator of the SPINTECH prof. A.Sidorenko opened the KICK-off Meeting on 21.09.2018 (links); Press conference: Dr. Belei and EC representatn, the Project Officer Dr. Pepa Krasteva presented the efforts of Moldova for strengthening of collaboration with EU - by opening of the meeting (rights).

The implementation plan for the SPINTECH was presented by coordinator of the project Anatolie Sidorenko while the general framework of the Twinning call was illustrated by Pepa Krasteva, EU Project Officer responsible for the project monitoring. It was present 35 participants at the meeting – members of the Advisory Board of the project, representatives of ministry, from radio, TV and press. Prof. A.Sidorenko and Dr. E.Belei were interviewed by Moldova1 (State TV Moldova), Radio-Moldova and news agency SPUTNIK-Moldova.

The Working Meeting +TrainingWorkshop took place on 05-06 March 2019, in IEEN, Chișinău, Moldova with 29 participants.

By opening of the SPINTECH workshop on 05 March 2019 journalist Andrey Petrik took Interview with Prof. Sidorenko about goals and importance for Moldova project SPINTECH, and with head of Department of Ministry of Education RM Dr. Tatiana Moraru, who opened the workshop and stressed the great importance of the EU project for Moldova at the press conference.

Representant of Ministry MECC Dr. Tatiana Moraru at the opening of the workshop on 05 March 2019

Intreview given at press conference was published in “SPUTNIK-Moldova” on 12 March 2019:

В Молдову приходит спинтроника: что это такое, и как она действует на практике В Кишиневе начала работу научно-практическая конференция, основной темой которой стала спинтроника, которая постепенно приходит на смену полупроводниковой электронике.

КИШИНЕВ, 6 мар – Sputnik, Андрей Петрик. "Нет предела совершенству" – эта старая, как мир, формула работает сегодня и в науке, в том числе в молдавской. Казалось бы, человечество давно подчинило себе информационные технологии, за несколько десятилетий вывело их на новый уровень.

Однако прогресс не стоит на месте, и те устройства, основанные на полупроводниковых системах (даже обычные ноутбуки, которые есть у каждого второго пользователя компьютеров), завтра могут стать информационным атавизмом.

Но мировая и молдавская наука не стоит на месте, и чтобы быть во всеоружии завтра, сегодня надо продумать стратегию замены устаревающих устройств, подготовить плацдарм для их совершенствования.

Научная конференция в Кишиневе

В Кишиневе начала работу научно-практическая конференция, посвященная развитию спинтроники – науки XXI века. У молдавских ученых уже сегодня есть конкретные наработки в этом направлении, которые интересны для реализации на европейском пространстве. Об этом корреспонденту Sputnik Молдова рассказал директор Института электронной инженерии и нанотехнологий, профессор, академик молдавской Академии наук Анатолий Сидоренко.

"Сегодня – важное событие и для нашего института, и для всего научного сообщества Молдовы. У нас проходит двухдневная конференция по проекту "SPINTECH" программы "Horizon-2020" (GrantAgreementno: 810144). На протяжении трех лет этот проект будет способствовать более глубокой интеграции Молдовы в научное пространство Европы", - рассказал ученый. Координатором проекта выступил институт, руководимый Анатолием Сергеевичем.

Европейское сообщество на научном форуме в Кишиневе представили профессор Стокгольмского университета (Швеция) Владимир Краснов, профессор университета Твента (Нидерланды) Александр Голубов, а также научный сотрудник компании “Intelligentsia” (Люксембург) доктор Скоччи.

Те достижения, которые на протяжении 20 лет были наработаны в Институте электронной инженерии и нанотехнологий, и послужили базой для этого проекта. А его целью является разработка новой элементной базы для микроэлектроники XXI века– спинтроники.

"Одна из главных задач Института – применение технологий спинтроники в промышленности, разработки микроэлектронных устройств нового поколения. Сегодня развитие полупроводниковой электроники достигло своего апогея и ограничено", - рассказал профессор Сидоренко.

Открыла конференцию начальник управления политики в сфере исследований и инноваций министерства образования, культуры и исследований РМ доктор Татьяна Морару. Чиновница подчеркнула: «Республика Молдова активно участвует в Рамочных программах ЕС по исследованиям и инновациям (а именно "Horizon-2020") и ошибочно думать, что Молдова не занимает свое место в европейской науке. Представители нашей страны показывают хорошие результаты на общеевропейском пространстве, а разработки молдавских ученых вызывают уважение европейских коллег».

«Сегодня ученые из Молдовы представлены на европейском пространстве, выходят туда с инновационными разработками и достойно представляют нашу страну. Сегодняшняя конференция – подтверждение этому", - отметила Морару.

План работы научно-практической конференции был более, чем насыщенным и интересным. Молдавские ученые и гости из-за рубежа посетили также столичный лицей им. Гоголя, где рассказали учащимся и педагогам о спинтронике, которая, видимо, совсем скоро станет не только инновационным направлением в науке, а ее буднями.
Report about this Press conference was published on site:
https://ru.sputnik.md/technologies/20190306/25079376/moldova-prikhodit-spintronika-deystvuet-na-praktike.html

Press conference C on 24.09.2019

Press conference by opening of the First SPINTECH Conference **"SPINTECH-NANO-2019: Limits of Nanoscience and Nanotechnologies"** (24-27 September 2019), organised in Moldova with participants from 15 countries all over the world. In press conference 4 talks were given: by coordinator of the SPINTECH project Prof. A.Sidorenko, by vice president of Academy of Sciences of Moldova Prof. S.Cojocaru, by Head of Department of Ministry MECC Dr.T.Moraru and by Ständige Vertreter der Bundesrepublik Deutschland bei der Europäischen Union Dr. O. Schulte., as shown in Photo:

Reportage about that presss-conference is available on site:
https://www.youtube.com/watch?v=Y0cva0jECf0

Press conference C on 08.09.2021

The SPINTECH project consortium organised a training workshop on "Artificial Neuronal Networks: from nanofabrication to deep-learning" in Chișinău during 7-9 Sept 2021 with participation of Prof. Isaak Bersuker from University of Texas, USA and Prof. Igor Lukyanchuk from Unversity of Amien, France. Press conference was organized on 08.09.21 (shown on photo below) with speech of Prof. Bersuker about importance of science for progress and such project as SPINTECH.

Press conference of A.Sidorenko, I.Bersuker and I.Lukyanchuk on 08 September 2021 in D.GHITU IEEN

Comprehensive details regarding the workshop and given press conference is available on site: https://www.youtube.com/watch?v=HZYMXzXPE4o.

9.1. Coverage about the project in TV media

3 TV documentaries have been held during the whole project: A on 27.01.2019, B on 24.03.2019 and C on 09.09.2021.

TV documentary A on 27.01.2019

Extended presentation of the Project SPINTECH was done for the program "Stiinta si Inovare" (Science and Innovation) of the Moldova-1, State TV. A.Sidorenko presented the main goals of the project, planned exchange visits, workshops, summer schools and expected results during the project implementation.

The weblink to the TV documentary is: https://www.youtube.com/watch?v=3rxRgma6oSQ

TV documentary B on 24.03.2019

On Monday the 22nd of March 2021, D. GHITU Institute of Electronic Engineering and Nanotechnologies hosted a SPINTECH consortium meeting in Moldova. The SPINTECH consortium partners namely Prof. Anatolie Sidorenko (D. GHITU Institute), Dr. Oleg Bujor (D. GHITU Institute), Prof. Alexander Golubov (UTWENTE) and Prof. Vladimir Krasnov (Stockholm University), presented and discussed the latest project results as well as the project implementation plan.

TV Interview with consortium members of the SPINTECH project, A. Sidorenko, A.A. Golubov and V.M. Krasnov about project SPINTECH was presented in the TV program "Stiinta si Inovare" of the State TV of the Republic, Moldova-1, demonstrated that interview on March 24th, 2019; weblink to the TV documentary: (https://www.youtube.com/watch?v=mLxZXuSban4)

TV documentary C on 09.09.2021

Interview with Prof. Isaak Bersuker 09.September 2021 - about prospects of the SPINTECH project results implementation for development of microelectronics and international collaboration in frame of such projects as SPINTECH.

TV program "Stiinta si Inovare" presented that interview in special issue, available on site: https://trm.md/ro/stiinta-si-inovare/stiinta-si-inovare-emisiune-din-17-octombrie-2021

10.1. Visits to schools and public open-days

2 school visits and 2 public open-days have been held during the whole project: A on 05.03.2018, B on 11.11.2019, C on 19.04.2021, and D on 11.02.2022. School visit A on 05.03.2019

Prof. A.Sidorenko, Prof.V.Krasnov and Prof.A.Golubov at the N.V.Gogol school #37 visit on 05.03.2019. It was organised by director of the school – by meeting with 60 high school students. A.Sidorenko, A.Golubov and V.Krasnov presented the new project SPINTECH, explaned what does mean "Spintronics" and attracted attention of the audience to the scientific work.

Public open-day B on 11.11.2019

The "Open Door Day" in Chisinau and hosted by D GHITU IE 11.11.2019

On Monday, 11th November 2019, D.GHITU Institute of Electronic Engineering, hosted their "Open Door Day", with many visitors from Chisinau, Moldova. More than 80 school-students from 3 Gymnasiums from the city visited the exposition of the Institute and its laboratories, being better acquainted with the research work performed alongside technologies and devices being used. The director of Institute, acad. Sidorenko Anatolie presented the EU-funded project as coordinator of the SPINTECH project and also introduced consortium partners: Stockholm University, Sweden and University of Twente, Netherlands. As part of the expectations for disseminating and promoting SPINTECH, this was an excellent outreach activity which focused on the interests of the general public. The event of the whole day took place from 9:00 till 17:00, and was organized in frame of celebration of the "World Science Day" activities.

The "Open-door day" 11.11.2019 in D.GHTU IEEN

Public open-day C on 19.04.2021

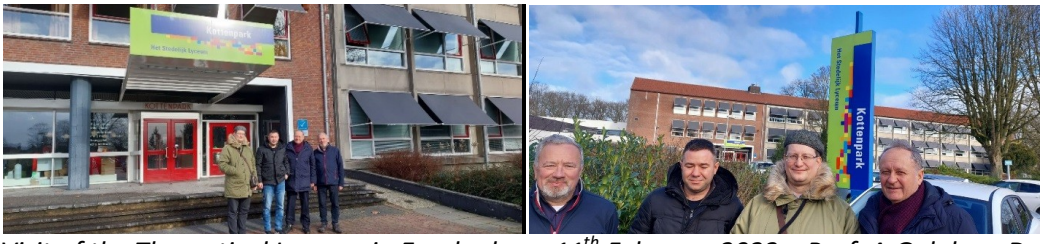
The SPINTECH project and the Association of Physicists of Moldova (SFM) organised on April 19, 2021 the open-door seminar in conference hall of D.GHITU IEEN with participation of people from 5 institutes: IEEN, Institute of Applied Physics, Technical University, Institute of Chemistry, Institute of Geology and Seismology. The aim of the seminar was to discuss a new direction of science and engineering – brain-like artificial neural networks and ethical problems related to that new area. Prof. Sidorenko, president of the Moldavian Physical Society, presented public lecture: "Quo Vadis? Ethics of Scientific Research: Artificial Neural Networks".

Prof. A.Sidorenko after presenting lecture"Quo Vadis? Ethics of Scientific Research: Artificial Neural Networks" at open-door seminar on 19.04.2021

A.Sidorenko gave interview, available on site: http://www.vedomosti.md/news/anatolij-sidorenko-proschityvat-vozmozhnye-rekombinacii-dlya

School visit D on 11.02.2022

During staff-exchange work in February 2022 in Twente, Prof. A.Golubov organised visit of the Theoretical Lyceum in Enschede of collaborators of D.GHITU IEEN – Prof. A.Sidorenko, Dr. O.Bujor and Dr. A.Prepelita, who presented to the high-school students the SPINTECH project and the role of the University of Twente in development of superconducting spintronics, attracted attention of the audience to the scientific work.



Visit of the Theoretical Lyceum in Enschede on 11th February 2022 – Prof. A.Golubov, Dr. O.Bujor, Dr. A.Prepelita, Prof. A.Sidorenko.

11.1. Some additional information about Outreach activity – organization of open-door events and national seminars:

1. Series of the Republican open-door seminars with the Logo **"Quo Vadis? Etics of the scientific research**" in a mixt format – Google-Meet on-line participants from Moldova and several countries, and off-line in conference hall of D.GHITU IE - here collaborators

of the Institute and from 5 other organizations – Institute of Applied Physics, Institute of Chemistry, Institute of Geology and Seismology, Technical University of Moldova and State Antihail Service of RM, and representatives of mass-media: State Television of Moldova (Moldova-1, journalist Elena Cecan), newspaper "Молдавские Ведомости» (News of Moldova, journalist Maria Buinciuc). Journalists provided interview with the lecturers and published them in newspapers and demonstrated in special TV-program "Stiinta si inovarea" (Science and Innovation).

AVIZ

Şedinţa Seminarului Republican de Fizică va avea loc

Luni, 14 iunie 2021, ora 11-00.

Şedinţa este organizată de Societatea Fizicienilor din Moldova în cooperare cu Institutul de Inginerie Electronică şi Nanotehnologii „D.Ghiţu" şi cu suportul Proiectului Internaţional "SPINTECH" (grant agreement # 810144).

Şedinţa va avea loc on-line în regim «video-conference».

Genericul seminarului:

Quo Vadis? Etica cercetărilor ştiinţifice - nanotehnologiile în luptă cu maladiile oncologice.

Prof. Fliur Macaev (Institutul de Chimie) prezintă raportul ştiinţific la tema: „Tehnologia Calului Troian - nanoparticule inteligente în lupta împotriva celulelor cancerogene".

Link pentru conectare la platforma-google.meet gasiţi in e-mail.

Academician A. Sidorenko, Preşedinte al SFM

2. Seminar Republican of the Moldavian Physical Society(SFM) – in D.GHITU IEEN, 19 April 2021, Chisnau, Moldova - **«Quo Vadis? Etics of the scientific research: artificial neural networcs»**- moderator acad.ASM Anatolie Sidorenko.

3. Seminar Republican of the Moldavian Physical Society (SFM), in D.GHITU IEEN, 14 Iune 2021, Chisnau, Moldova – **«Quo Vadis? – Etics of the scientific research: nanotehnologies agains cancer**» - moderator Prof. Fliur Macaev**.**

4. Seminar Republican of the Moldavian Physical Society (SFM), in D.GHITU IEEN, 08 September 2021, Chisnau, Moldova – **«Quo Vadis? – Etics of the scientific research: Jahn–Teller a pseudo-Jahn–Teller Effects»** - moderator Acad. ASM**,** Professor of the University of Texas (USA) Isaac Bersuker.

12.1. Participation in expositions

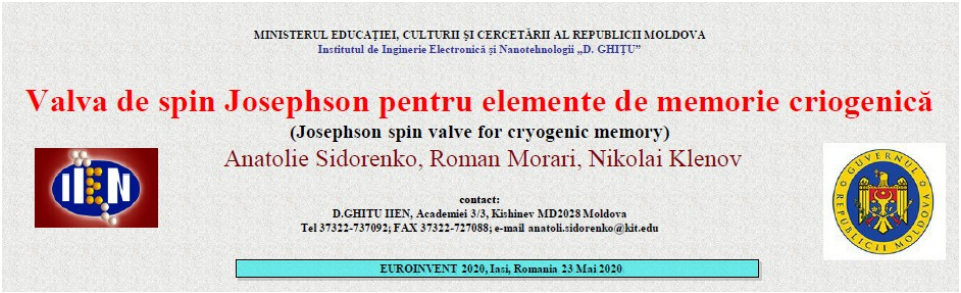
One of the imortant part of the outreach activity was participation of the IIEN team members in exhibitions, presenting elaborated technologies of functional hybrid S/F-nanostructures and ferromagnetic nanoparticles fabrication, and implementation them for spintronic devices, also for other industrial goals. Elaborated devices and technological processes were presented in 2020 at two international exhibitions: "Fabricat in Moldova" (29.01.20-02.02.20, Chisinau, Moldova), and at "EUROINVENT-2020" (23.05.2020, Iasi, Romania).

Presented results were appeciated by vistors and by the Jurie, and were aworded by diploms and medals: with 2 Gold medals and 1 silver medal, shown below.

13.1. Diploms and awards

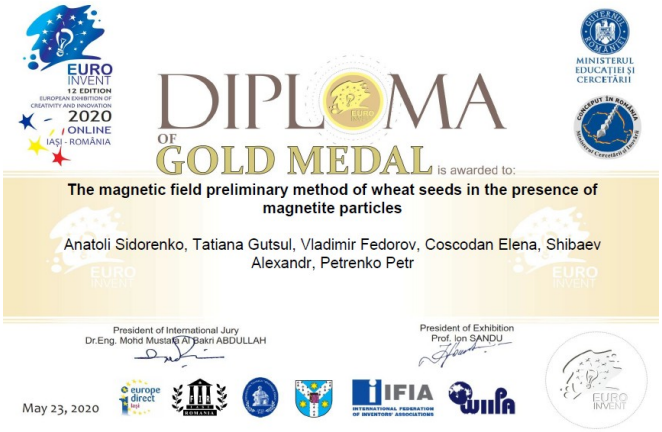
Diplom obtained at international exhibition "Fabricat in Moldova" for presented innovations:

Diploms and medals obtained at international exhibition "EUROINVENT-2020" for presented innovations:



This Innovation is based on 2 patents of Moldova, obtained within the project implementation:

1. Hotarire de inregistrare a desenelor si modelelor si modelelor industrial. Nr.depozit: f20190041, Data depozit: 2019.05.23. Data publicarii: 2019.09.30. Vacuumetru. BELOTERCOVSCHII Igori, MD, SIDORENKO Anatolie, MD; CONDREA Elena, MD; MORARI Roman, MD.
2. Cerere de brevet de scurtă durata. №2063 din 2020.06.16. BELOTERCOVSCHII Igori, MD; SIDORENKO Anatolie, MD; CONDREA Elena; MORARI Roman, MD. Vacuummetru termoelectric.



14.1. Other activities

Participation of SPINTECH in the European anti-COVID Hackathon on 24-30 April 2020

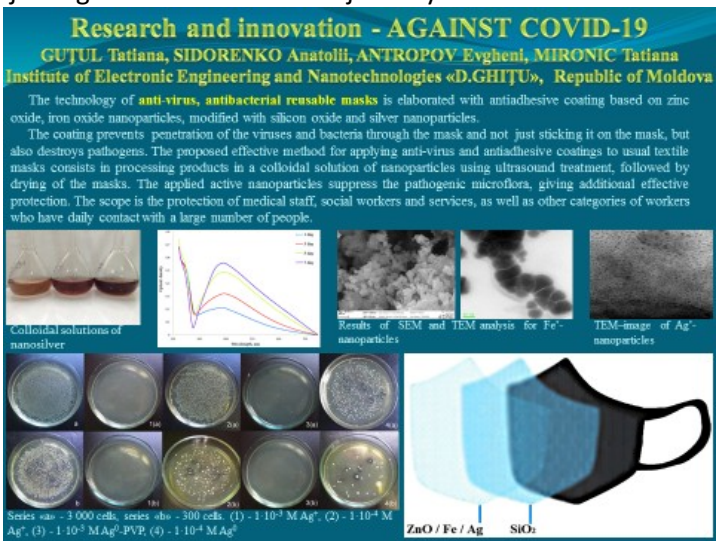
Moderator of the European anti-COVID Hackathon Daniel Wallner wrote:

daniel wallner 10:06

Good morning community! We did it! Our hackathon finally comes to an end - we hope

you all had a good time with us we sure did! With 2140 numbers of projects YOU created, you can be really proud of yourselves We will come back to you on

Thursday 30th of April 11 AM CEST with our award ceremony and the results Thank you for joining us in this Hackathon-journey!



SPINTECH project members - participants of the EU Anti-COVID Hackathon awarded on 30th April 2020 with diploma for the elaboration "SPINTECH-Mask"

Publication in press about anti-COVID elaboration of the SPINTECH team:
Молдавские ученые разработали два проекта защиты медиков от COVID-19
18:39 02.05.2020

Алена Матвеева

Тема:

Коронавирус нового типа распространяется по миру (1011)

Отечественные исследователи откликнулись на непростую ситуацию, сложившуюся в секторе здравоохранения и представили варианты "умного щита" для тех, кто в силу профессиональных обязанностей подвержен наибольшему риску инфицирования.

КИШИНЕВ, 2 мая - Sputnik. В Молдове число заражений коронавирусом нового типа среди медицинских работников перешагнуло за тысячу. Пока большая часть жителей страны пребывает в самоизоляции, именно медики находятся на передовой в борьбе с инфекцией, и шансы заразиться самим у них довольно высоки. Отечественные люди науки откликнулись на непростую ситуацию, сложившуюся в секторе здравоохранения, и представили свои разработки, которые помогут сотрудникам медицинской системы защититься от COVID-19.

"Ученые Молдовы стараются помочь врачам тем, что в наших силах. Мы откликнулись на ситуацию, которая сложилась в республике. Мы думали об этом и с помощью врачей включились в проблему", - рассказал Sputnik директор Института электронной инженерии и нанотехнологий Молдовы академик Анатолий Сидоренко.

Один из проектов, предложенный учеными, касается санации медперсонала. В основу метода взята идея, которая испытывалась в Ворниченской туберкулезной больнице для лечения пациентов облучением ультрафиолетом.

https://ru.sputnik.md/society/20200502/30105560/moldavskie-uchenye-predstavili-dva-proekta-dlya-zaschity-medikov-ot-covid-19.html

15.1. Outreach events

SPINTECH outreach event - visit of the Castel MIMI:

Prof. A.Sidorenko organised SPINTECH outreach event within SPINTECH winter school (*10-11 December 2021, Chișinău, Moldova)* for participant - the external session in the castle MIMI on 11.12.2021

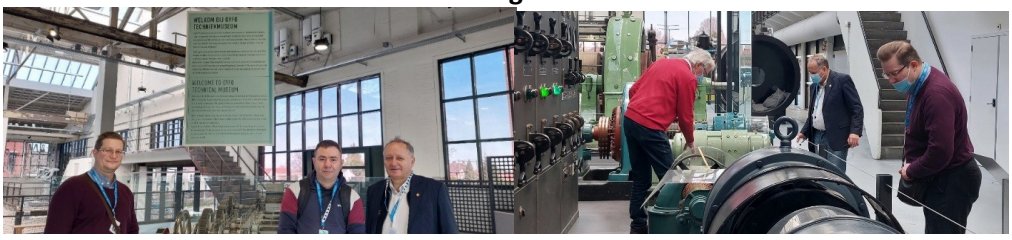
Outreach event in national Complex Cricova:

SPINTECH consortium organised outreach event within SPINTECH Winter School "Spintronics highlights: Artificial Superconducting Synapses and Neurons" (21-22 January 2022, Chișinău, Moldova) - external session on 22.01.22 in "Cricova" national complex of Moldova

Outreach event in Nationalmuseum Stockholm:

Prof. V.Krasnov organized outreach activity in frame of the SPINTECH-school (03-04 February 2022) - the external session, visit on 04.02.2022 the Nationalmuseum (Södra Blasieholmshamnen 2, 111 48 Stockholm.), increasing the general level of IEEN collaborators, making acquaintance with the grate masterpieces of the world, collected and presented in Stockholm.

Outreach event in Technical Museum Hengelo:



Prof. A.Golubov organized outreach event in frame of the SPINTECH-winter school (10-12 February 2022) - the external session, visit on 12.02.2022 of the Technical Museum Hengelo, for extension of general knowledge of the project participants

16.1. Summing up of the SPINTECH project results

As the result of three and half years SPINTECH project implementation, were achieved:

- Increasing of the skills and professional level of the D.GHITU IEEN collaborators in spintronics, thank to the staff-exchange working visits: 16 collaborators of the Institute worked in Uni-Twente and in Uni-Stockholm, learning the newest technologies of samples fabrication, the methods of their characterization and measurements at ultra-low temperatures. That increasing has a quantitative parameter: Hirsh – index of the Institute increased 2 times, Hirsh index of the coordinator, Prof. Anatolie Sidorenko increasd from Hi-13 at the start of the project to Hi-23 in 2022.
- 7 students, participated in the project, defended their diploma;
- 3 – gained Master title;
- 2 PhD thesis are preparing in frame of the project;

- IIEN won in 2020 National project “Functional nanostructures and nanomaterials for industry and agriculture” of the State Program RM (2020-2023);
- In 2022 two proposals of new project are submitted to the HORIZON-Europe program: **HORIZON-CL4-2021-DIGITAL-EMERGING-02-16: Basic Science for Quantum Technologies (RIA)**, project “QUPOCOS” in January 2022 and “LAPLAS” in March 2022 as the follow-up result of the SPINTECH project.

One can conclude, that the goal of the SPINTECH project ”boosting of excellence” of the D.GHITU Institute of Electronic Engineering and Nanotechnologies was achieved as the main result of the project implementation.

Attachments

MINISTERUL EDUCAȚIEI, CULTURII ȘI CERCETĂRII

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 810144

SPINTECH

"Boosting the scientific excellence and innovation capacity in spintronics of the D. GHITU Institute of Electronic Engineering and Nanotechnologies of Moldova"

SPINTECH

– goals, achievements, networking

Synapses based on superconductor-ferromagnet heterostructures fundamentals and fabrication.

coordinator of the project

acad. Sidorenko Anatolie

SPINTECH Training workshop "Artificial Synapses for Spintronics", *24-25 February 2022, Chișinău, Moldova*

UNIVERSITY OF TWENTE.

Stockholm University

Institute of Electronic Engineering and Nanotechnologies, Chisinau, Moldova – in a tight collaboration with partners:

Valdimir Krasnov
Stockholm University

Alexander Golubov,
Twente University

Mikhail Kupriyanov, Nikolai Klenov, Moscow, Russia

Vasily Stolyarov, MIPT, Dolgoprudny, Russia

Alexander Vakhrushev Izhevsk, Russia

Lenar Tagirov Kazan, Russia

Bernhard Keimer Yurii Khadukov, Stuttgart, Germany

Horst Hahn Karlsruhe, Germany

Networking:

Site of SPINTECH - https://www.h2020-spintech.eu/

partner- EU project: MELON (Amienne, France) - Igor Lukyanchuk https://www.melon.ferroix.net/

Goals of the HORIZON-2020 project

• The overall aim of the "SPINTECH" project is:

boosting the scientific excellence and innovation capacity of the D. GHITU Institute of Electronic Engineering and Nanotechnologies in the field of spintronics

– especially in the development of advanced technologies for design and production of superconducting spintronic devices and base elements for novel computer with non-von Neumann architecture – brain like artificial networks

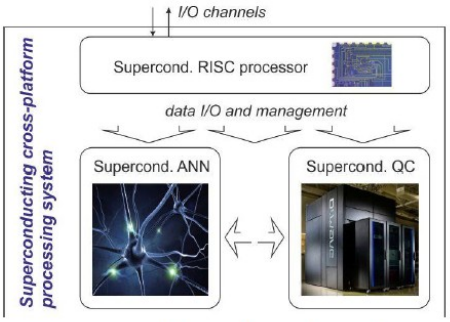
Motivation of the work: **Limits of semiconducting technology**

- **LARGE size and huge Power consumption**

After O. A. Mukhanov, HYPRES Inc, USA

Superconducting solution -

Rapid and energy-efficient platform for neural network and quantum computer with non-von Neumann architecture



The same base elements!

Temperature levels of operating ANN and Quantum Computer

Scientific Colaboration –staff-exchange: 16 members of IEEN -42 person-months worked in SU and U-Twente

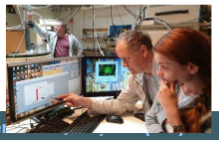
- University of TWENTE - Caracterization of morphology and structure of SF-samples organization of scientific events - seminars, winter- and summer schools.
- Universitaty of Stockholm – Preparation of samples using the FIB technique

on plasma „Oxford Plasmalab 100" and "Focusing Ion Beam lithography" (FIB),

Organization together with IEEN , Twente various scientific events –

2 international conferences, 3 winter and 3 summer schools,

7 targeted training workshops and a lot of seminars



Training workshops, conferences and summer schools

- 7 planned training workshops in Chisinau, Twente and Stockholm and 2 international conferences were organized in Chisinau:

< In September 2019

And

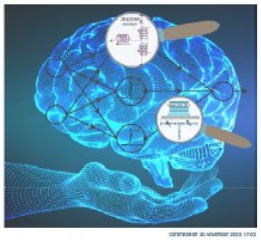
In September 2021 >

Publication of planned book after the conferences:

BEILSTEIN JOURNAL OF NANOTECHNOLOGY

Functional nanostructures for electronics, spintronics and sensors

Edited by Anatolie S. Sidorenko



- Was published 30 November 2020

BEILSTEIN JOURNAL OF NANOTECHNOLOGY

Thematic Issue:

Intrinsic Josephson effect and prospects of superconducting spintronics

Editors:

Prof. Anatolie Sidorenko, Institute of Electronic Engineering and Nanotechnologies, Moldova

Prof. Vladimir Krasnov, University of Stockholm, Sweden

Prof. Horst Hahn, Institute of Nanotechnology, Karlsruhe Institute of Technology, Germany

Will be - published in May 2022

Outreach activity – organization of open-door events and national seminars :

1. Seminar Republican al Societatii Fizicienilor Moldovei (SFM). IEEN Chisinau, Moldova, 19 April 2021, Chisnau, Moldova - «**Quo Vadis? Этика научного поиска - искусственные нейрональные сети**»- acad.ASM Anatolie Sidorenko.
2. Seminar Republican al Societatii Fizicienilor Moldovei (SFM). IEEN Chisinau, Moldova, 14 Iune 2021, Chisnau, Moldova – «**Quo Vadis? - Etica cercetărilor științifice - nanotehnologiile în luptă cu maladiile oncologice**» - Prof. Flur Macaev.
3. Seminar Republican al Societatii Fizicienilor Moldovei (SFM). IEEN Chisinau, Moldova, 08 September 2021, Chisnau, Moldova – «**Quo Vadis? - Etica cercetărilor științifice - Jahn–Teller and Pseudo-Jahn–Teller Effects**» - Acad. ASM, Professor of the University of Texas (USA) Isaac Bersuker.

AVIZ

Şedinţa Seminarului Republican de Fizică va avea loc

Luni, 14 Iunie 2021, ora 11-00.

Şedinţa este organizată de Societatea Fizicienilor din Moldova în cooperare cu Institutul de Inginerie Electronică şi Nanotehnologii „D. Ghiţu" şi cu suportul Proiectului Internaţional "SPINTECH" (grant agreement # 810144).

Şedinţa va avea loc on-line în regim ovideo-conferinţe».

Genericul seminarului:

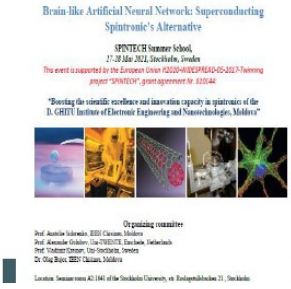
Quo Vadis? Etica cercetărilor științifice - nanotehnologiile în luptă cu maladiile oncologice.

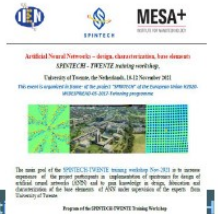
Prof. Flur Macaev (Institutul de Chimie) prezintă raportul ştiinţific la tema: „Tehnologia Calului Troian - nanoparticule inteligente în lupta împotriva celulelor canceroguna".

Link pentru conectare la platforma google.meet gasiti in e-mail.

Academician A. Sidorenko, Preşedinte al SFM

Organized 2 conferences and 6 schools (3 summer, 3 winter)





Increased excellence

Summing up

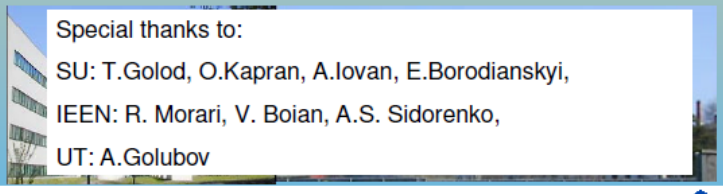
- As the result of three and half years SPINTECH project implementation, the main goals, announced in the project proposal and in the Grant Agreement are achieved, in particular:
- It was achieved increasing of the skills and professional level of the D.GHITU IEEN collaborators in spintronics, thank to the staff-exchange working visits: 16 collaborators of the Institute worked in Uni-Twente and in Uni-Stockholm, learning the newest technologies of samples fabrication, the methods of their characterization and measurements at ultra-low temperatures. That increasing has a quantitative parameter: Hirsh – index of the Institute increased 2 times, Hirsh index of the coordinator, Prof. Anatolie Sidorenko increasd from Hi-13 at the start of the project to Hi-23 in 2022.
- 7 students, participated in the project, defended their diploma,
- 3 – gained Master title,
- 2 PhD thesis are preparing in frame of the project
- IIEN won in 2020 National project "Functional nanostructures and nanomaterials for industry and agriculture" of the State Program RM (2020-2023).
- In 2022 two proposals of new project are submitted to the HORIZON-Europe program: HORIZON-CL4-2021-DIGITAL-EMERGING-02-16: Basic Science for Quantum Technologies (RIA), project "QUPOCOS" in January 2022 and "LAPLAS" in March 2022 as the follow-up result of the SPINTECH project.

One can conclude, that the aim "boosting of excellence" of the D.GHITU Institute of Electronic Engineering and Nanotechnologies was achieved as the main result of the SPINTECH project implementation.

In-situ analysis of magnetic states in small S/F heterostructures

Vladimir Krasnov

Experimental Condensed Matter Physics Group
Department of Physics
Stockholm University
AlbaNova University Center
SE-10691 Stockholm, Sweden



Special thanks to:

SU: T.Golod, O.Kapran, A.Iovan, E.Borodianskyi,

IEEN: R. Morari, V. Boian, A.S. Sidorenko,

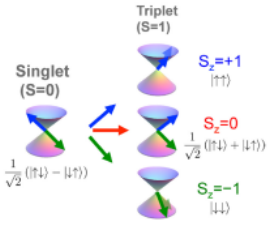
UT: A.Golubov

The work was supported by the European Union H2020-WIDESPREAD-05-2017-Twinning project "SPINTECH" under grant agreement Nr. 810144.

SPINTECH Summer school, 27-28 May 2021, Stockholm

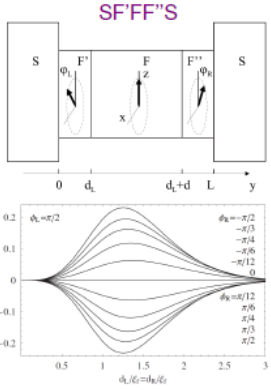
Generation of odd-frequency spin-triplet order parameter in S/F heterostructures

A. I. Buzdin, Rev. Mod. Phys. **77**, 935 (2005).
F. S. Bergeret, et al., Rev. Mod. Phys. **77**, 1321 (2005).
Y. Asano, et al, Phys. Rev. B **76**, 224525 (2007).
Ya. V. Fominov, et al., JETP Lett. **91**, 308 (2010).
A. S. Mel'nikov, et al., Phys. Rev. Lett. **109**, 237006 (2012).
And many more…



From M. Eschrig, Rep.Prog.Phys. 78, 104501 (2015)

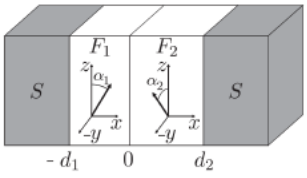
SF'FF"S

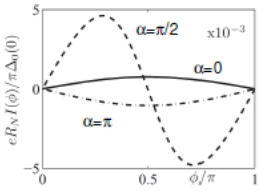


Houzer, Buzdin, Phys. Rev. B **76**, 060504(R) (2007).

+ Transistor-like operation!
- Complex behavior, many degrees of freedom, domains, size, shape anisotropy…
Need tools for in-situ control to prove the triplet nature

A much simpler case: SFF´S



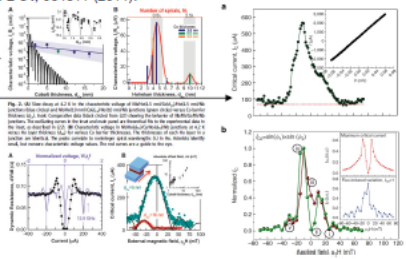


A significant tunable 2nd harmonic current !

L. Trifunovic et al, Phys. Rev. B **84**, 064511 (2011).

MANY experimental efforts:

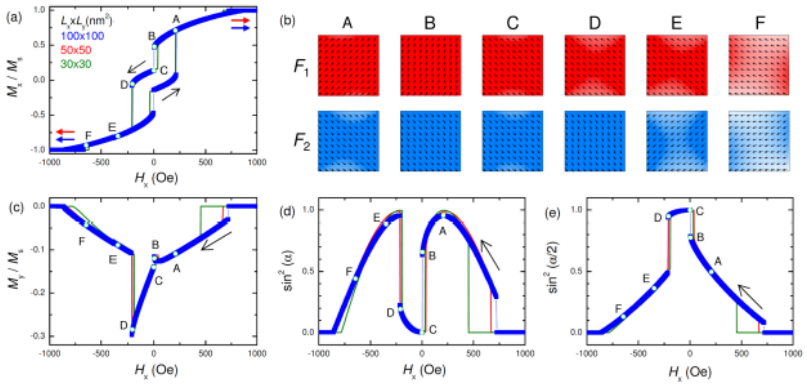
J.W. A. Robinson, et al, Science **329**, 59 (2010).
T. S.Khaire, et al., Phys. Rev. Lett. **104**, 137002 (2010).
N. Banerjee, et al., Nat. Commun. **5**, 4771 (2014).
W. M. Martinez et al,. Phys. Rev. Lett. **116**, 077001 (2016).
J. A. Glick, et al., Sci. Adv. **4**, eaat9457 (2018).
K. Lahabi, et al., Nat. Commun. **8**, 2056 (2017).
O. Vávra, et al., AIP Adv. **7**, 025008 (2017).
D. Lenk, et al., Beilstein J. Nanotechnol. **7**, 957 (2016).
+ Many more…



A. S. Mel'nikov, et al., Phys. Rev. Lett. **109**, 237006 (2012).

Both singlet and triplet
How to distiguish and prove?

What to expect? Numerical modeling of SFF'S spin valves using micromagnetic simulations: Monodomain case



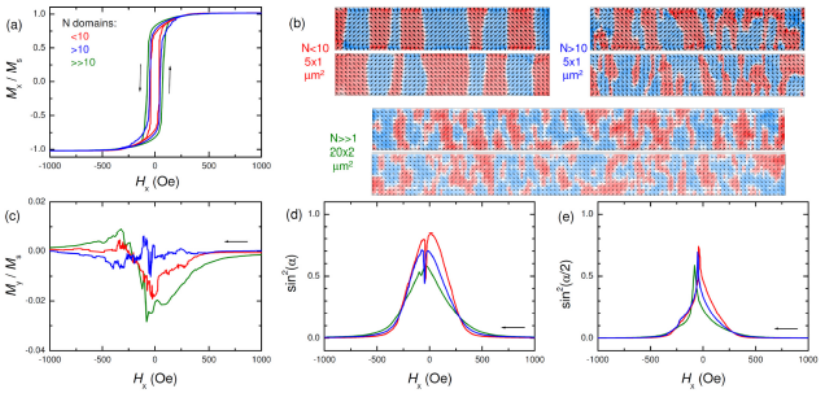
Clear distinction: Triplet current Singlet current

Singlet: **One peak** in the AP state, $\alpha=\pi$, corresponds to the clear intermediate $M(H)$ **step**

Triplet: **Two peaks** in the non-collinear states, $\alpha=+\pi/2, -\pi/2$.

A. Iovan and V. M. Krasnov, Phys. Rev. B **96**, 014511 (2017).

Multi-domain cases



Unclear distinction: Triplet current Singlet current

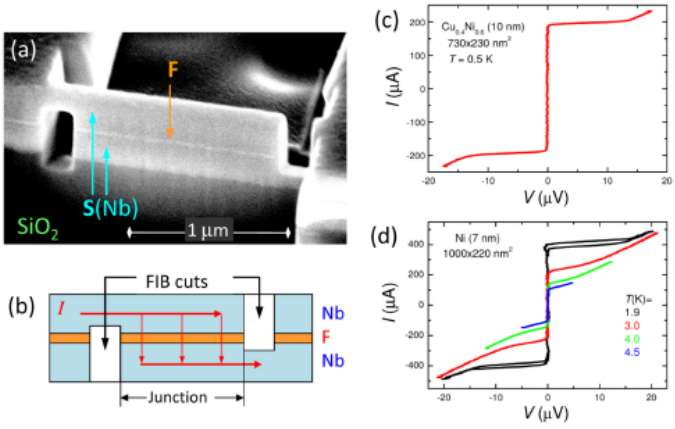
Singlet: **One peak**, but no intermediate $M(H)$ step

Triplet: **Two peaks** merge in one.

Details depend on geometry, sizes, shapes.

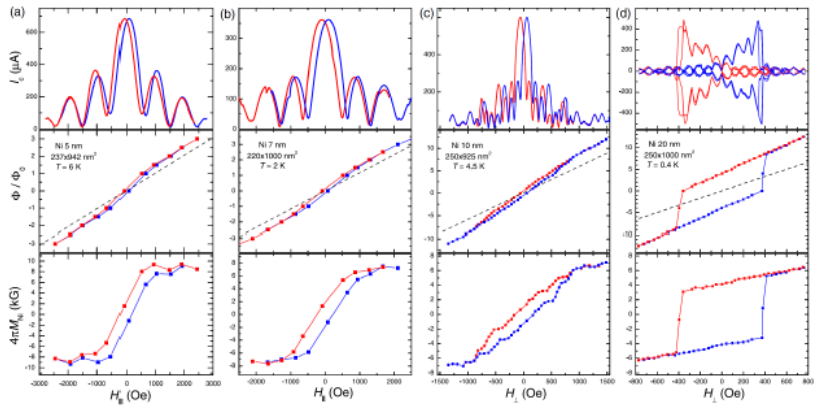
A. Iovan and V. M. Krasnov, Phys. Rev. B **96**, 014511 (2017).

I. Experimental analysis of nano-scale SFS junctions



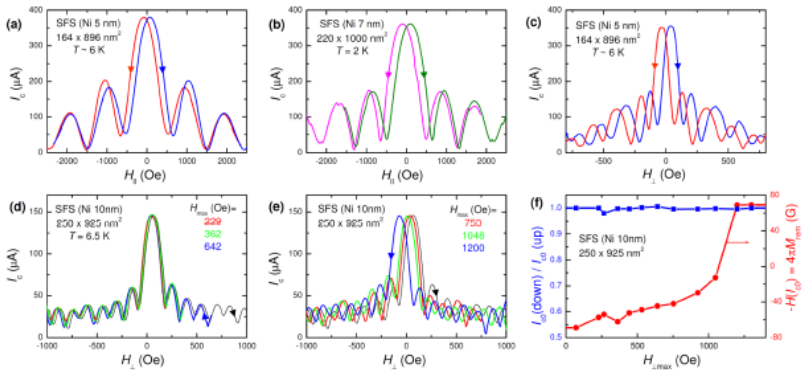
O. Kapran, et al., PRB 103, 094509 (2021)

In-situ characterization by Absolute Josephson Fluxometry (AJF)
Nb/Ni/Nb junctions



O. Kapran, et al., PRB 103, 094509 (2021)

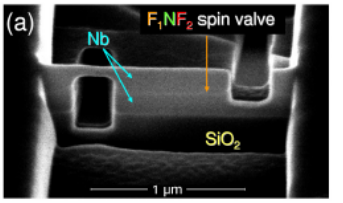
In-situ characterization by the First Order Reversal Curve (FORC) analysis
Nb/Ni/Nb junctions

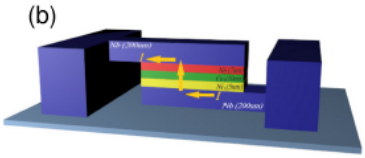


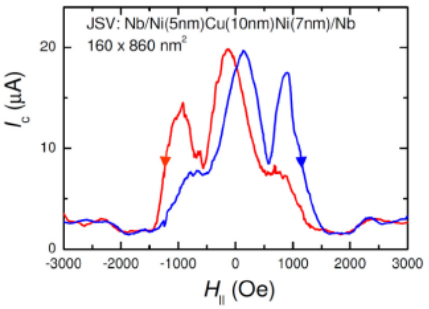
Trivial hysteresis: Just a shift of $I_c(H)$ patterns without distortion. Follows M(H) curve of the F-layer. No domains. Singlet current only!

O. Kapran, et al., PRResearch 2, 013167 (2020)

II. Experimental analysis of nano-scale SFF'S Josephson spin valves
Nb/Ni_1/Cu/Ni_2/Nb







Different from SFS:
Double peak!

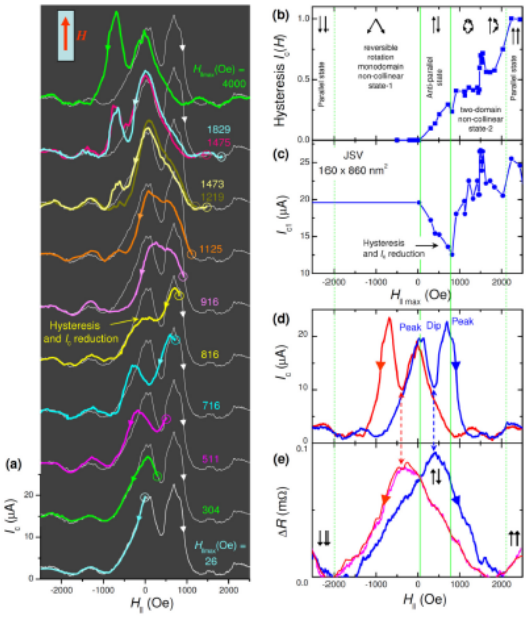
O. Kapran, et al., PRResearch 2, 013167 (2020)

In-situ characterization by FORC and MR
$Nb/Ni_1/Cu/Ni_2/Nb$ Josephson spin-valves

- Clear correlation between the dip in $I_c(H)$ and the peak in MR in the AP state $\alpha=\pi$. (singlet current)

- Two peaks arround in non-collinear states $\alpha=+\pi/2,\ -\pi/2$ (triplet current)

O. Kapran, et al., PRResearch 2, 013167 (2020)



Conclusions:

Analysis of the triplet state requires in-situ characterization of magnetic states in complex nano-devices.
Depends on:
size, shape, thicknesses, composition, structure (dirty-clean), domains…

We demonstrated in-situ characterization techniques:
- Magnetoresistance
- Absolute Josephson Fluxometry
- First order reversal curve analysis

* Obtained evidence for controllable monodomain remagnetization of Josephson spin valves

* Unambiguous evidence for existence of **both** triplet (~70 %) and singlet (~30%) supercurrents through a strong ferromagnet Ni.

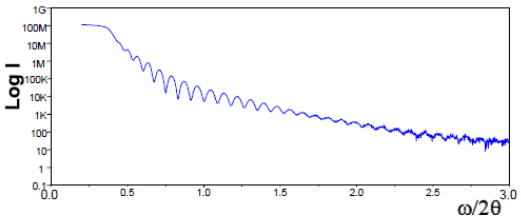
The work was supported by the European Union H2020-WIDESPREAD-05-2017-Twinning project "SPINTECH" under grant agreement Nr. 810144.

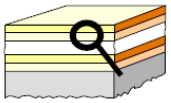
SPINTECH

X-ray Scattering Tools for the Characterization of Layered Structures

Vladimir Kogan, Joachim Woitok

SPINTECH - TWENTE training workshop 2021,
University of Twente, 20-21 October 2021





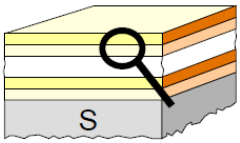
DANNALAB Materials Analysis by X-Ray Diffraction

Contents

- Introduction in the analytical needs of layered structures
- What you need to know about XRR
- How does the XRR analysis work
- The role of roughness
- Examples (including estimations Nb/Co)
- Summary

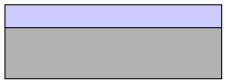
Thin films

Thin film(s):	layer(s) of material(s) ranging from fractions of nanometers (nm) to micrometers (µm) in thickness deposited on a substrate

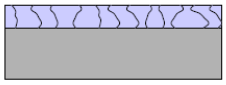


- crystalline
- poly-crystalline
- amorphous

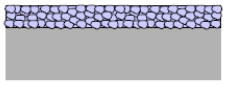
Relevant thin film types



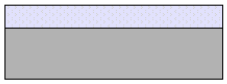
Nearly perfect epitaxy (thin film orientated to substrate parallel and perpendicular) – **GaAs** based



Imperfect epitaxy (thin film partially orientated to substrate parallel and perpendicular) – **GaN**



Textured polycrystalline (orientation unrelated to substrate but defined by growth) – **CdTe**, **CIGS**



Non-crystalline layers (no correlation beyond a bond length) – **amorphous Si, nano-Si**

4

Film properties of interest

- geometry (thickness, …)
- topography (roughness, sub-micro structures)
- chemistry (elements, composition, bonds)
- crystallography (structure, texture, defects)
- mechanical prop. (stress, hardness, density)
- optical prop. (colour, refr. index, scattering)
- electrical prop. (conductivity, permittivity, …)
- …

5

X-ray methods for thin films and layers

X-ray Reflectometry (XRR)
- Thickness, density, surface roughness
- Lateral and depth correlation

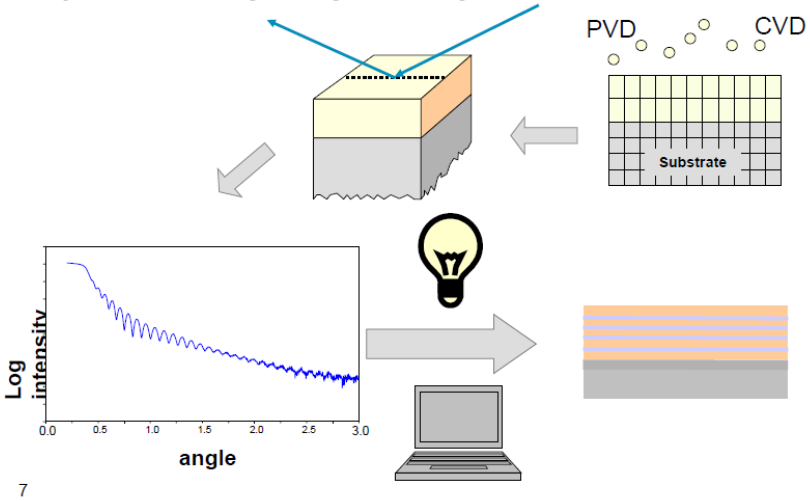
In-plane Scattering
- Nano-layers
- Nano-structures
- In-plane properties

High-Resolution Diffraction
- Orientation
- Epitaxy, lattice mismatch
- Phase composition
- Thickness
- Curvature

Texture Measurements
- Orientation of grains

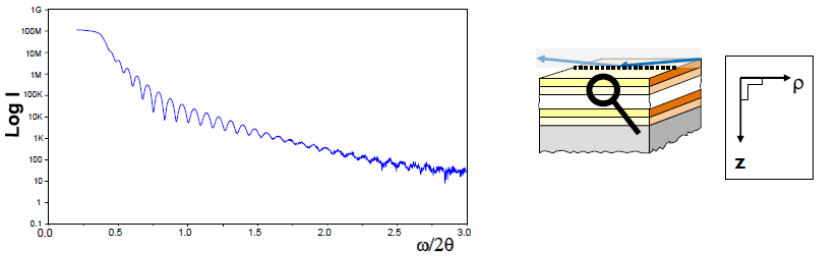
6

Steps in the X-ray analysis of layered structures



7

X-ray reflectometry



- Determination of layer thicknesses and densities (also roughness)
- Non-destructively, no limitation to sample crystallinity
- Detection of very thin layers (down to 1 nm)

8

X-ray reflectometry performance

Reflectometry:

- density: ± 1-2 %
- thickness: ± 0.5- 1 % (max. about 1000 nm)
- (roughness: model dependent (reproducibility 5%))

Alternative methods:

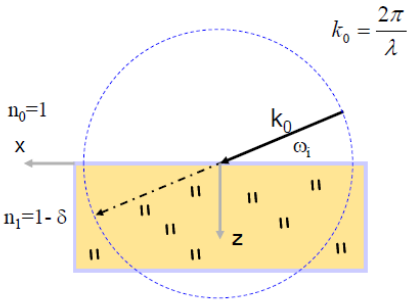
- density: RBS, refractive index (-)
- thickness: optical methods, TEM (-)
- roughness: interferometry, AFM, profilometry (only surfaces)

The X-ray index of refraction

n= 1-δ - iβ

$$\delta = \frac{r_e \cdot N_A}{2\pi}\lambda^2\rho\frac{Z+f'}{A}$$

$$\beta = \frac{r_e \cdot N_A}{2\pi}\lambda^2\frac{\rho}{A}f'' = \frac{\mu\lambda}{4\pi}$$



Numerical examples

	density [g/cm^{-3}]	$\delta \cdot 10^6$	$\beta \cdot 10^6$
Si	2.32	7.57	0.17
SiO_2	2.26	7.33	0.09
Nb	8.57	24.10	1.61
Co	8.90	23.84	3.41
Cu	8.96	24.39	0.58
W	19.3	45.73	4.07

Cu $K\alpha_1$: 0.15406 nm

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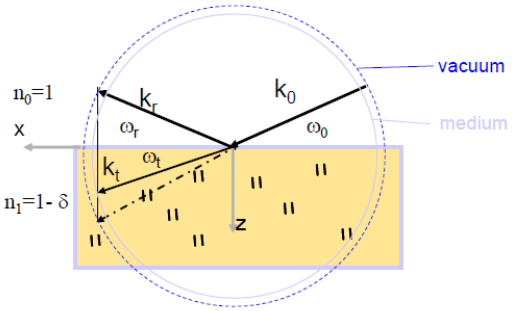
Boundary conditions at the interface



$$k_0 = \frac{2\pi}{\lambda}$$

$$k_t = \frac{2\pi}{\lambda} n_1 = k_0 n_1$$

12

Continuity at the interfaces

reflected beam $k_0 \cos \omega_0 = k_r \cos \omega_r$

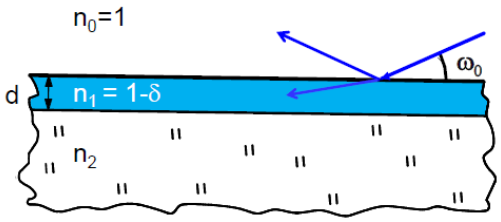
$k_0 = k_r \Rightarrow \omega_0 = \omega_r$ specular reflection

transmitted beam $k_0 \cos \omega_0 = k_t \cos \omega_t$ $k_t = n_1 k_0$

$n_0 \cos \omega_0 = n_1 \cos \omega_t$ Snell's law

13

Consequence of X-ray refraction



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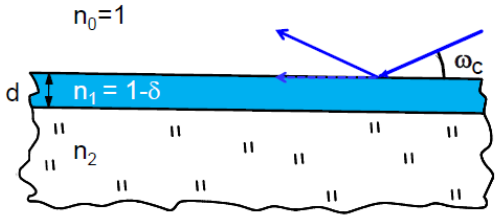
Total external reflection



Critical angle

$(\omega_t = 0)$

$$\cos \omega_C = n_1$$

$$\omega_C = \sqrt{2\delta}$$

15

Numerical examples

	density [g/cm^{-3}]	$\delta \cdot 10^6$	ω_c [°]
Si	2.32	7.57	0.223
SiO_2	2.26	7.33	0.219
Nb	8.57	24.1	0.398
Co	8.9	23.8	0.396
Cu	8.96	24.28	0.413
W	19.3	45.73	0.548

Cu $K\alpha_1$: 0.15406 nm

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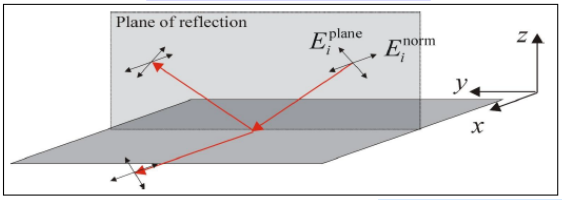
Fresnel equations

$$\vec{E}(\vec{r},t) = \vec{A}\exp(i(\vec{k}\vec{r} - \omega t))$$



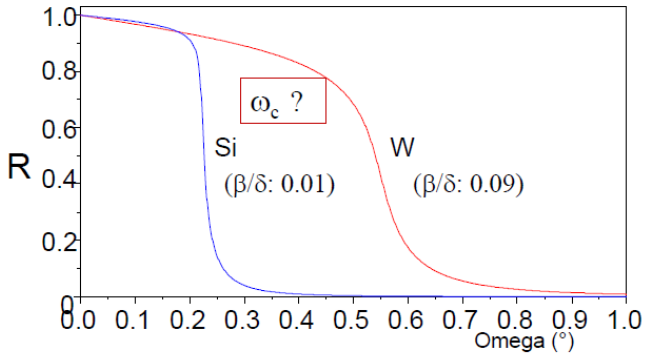
$$r_{j-1,j} = \frac{A_r}{A_i} \qquad R = \left|r_{j-1,j}\right|^2$$

$$t_{j-1,j} = \frac{A_t}{A_i} \qquad T = \left|t_{j-1,j}\right|^2$$

1	$\omega_0 < \omega_c$
$\sim 1/\omega_0^4$	$\omega_0 > 1.5\omega_c$

17

Understanding the critical angle

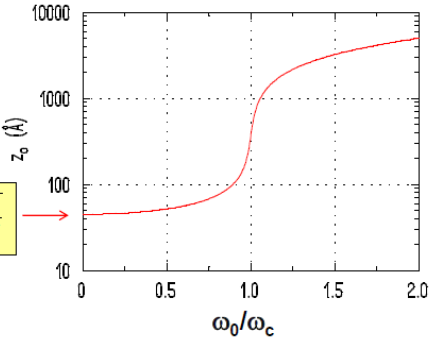


18

Penetration depth

Si: 32 Å
Co: 18 Å

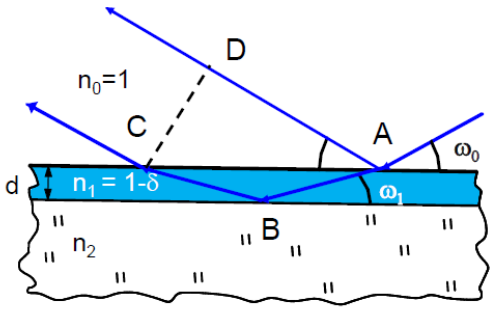
$$z_{00} = \frac{1}{2\pi}\sqrt{\frac{\pi A}{N_a r_e \rho Z}}$$



$$z_0 = \frac{\lambda\sqrt{2}}{2\pi}\left[\sqrt{(\omega_0^2 - 2\delta_1)^2 + 4\beta_1^2} - (\omega_0^2 - 2\delta_1)\right]^{-1/2}$$

20

Thickness fringes



$$\Delta = (\overline{AB} + \overline{BC}) \cdot n_1 - \overline{AD}$$

$$\Delta = 2 \cdot d \cdot n_1 \cdot \sin\omega_1$$

$$\approx 2 \cdot d \cdot \omega_1 = 2 \cdot d \cdot \sqrt{\omega_0^2 - 2\delta_1}$$

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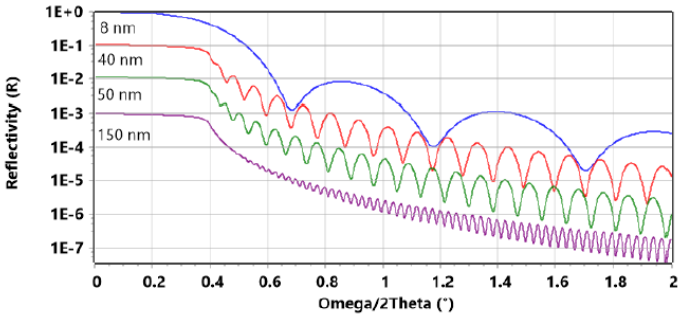
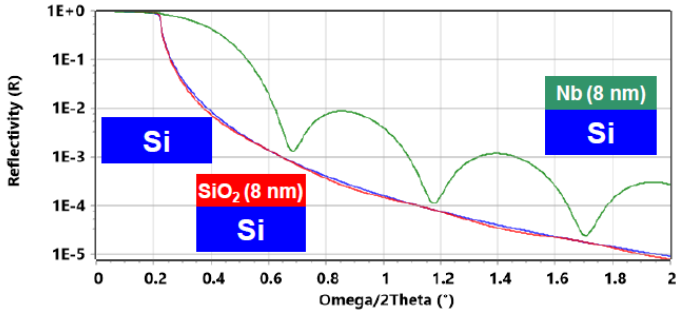
Thickness fringes XRR

Nb layer on Si substrate



22

Density contrast



Si: 2.32 SiO_2: 2.26 Nb: 8.57 g/cm^3

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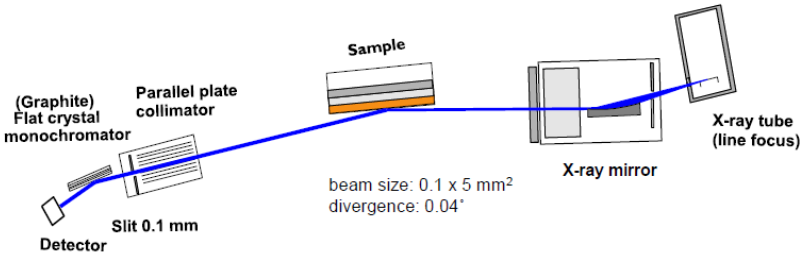
Typical XRR setup



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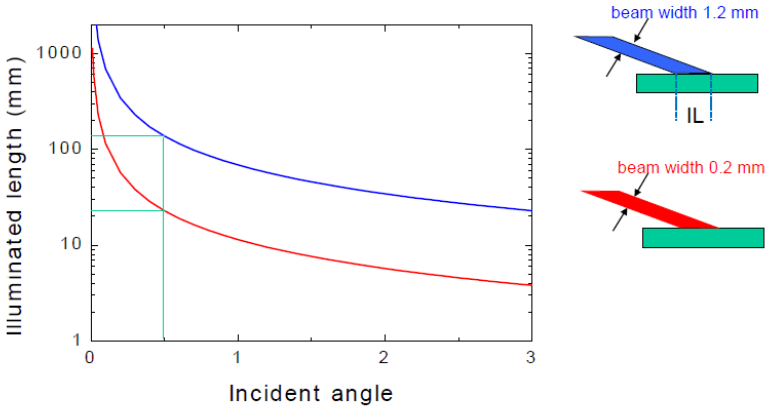
Sample illumination



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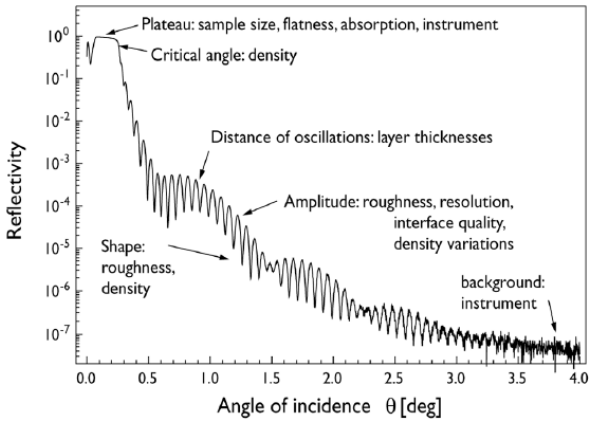
Information content of a XRR curve



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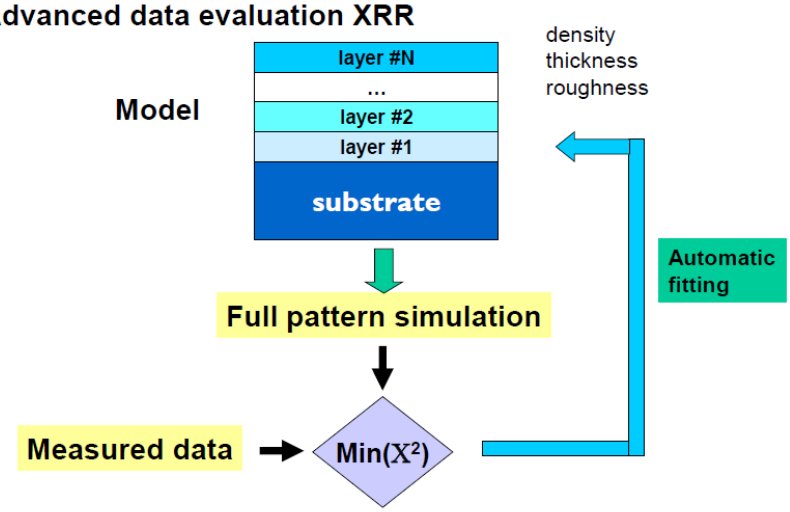
Advanced data evaluation XRR



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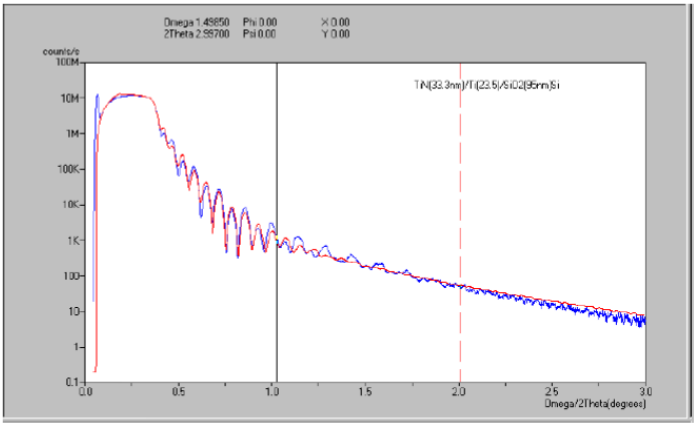
Example – Si/SiO_2(95nm)/ Ti(23.5nm)/TiN(33.3nm)



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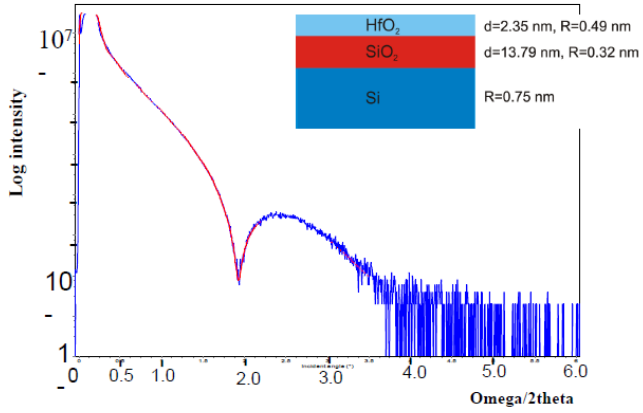
Example: Ultra thin layer



30

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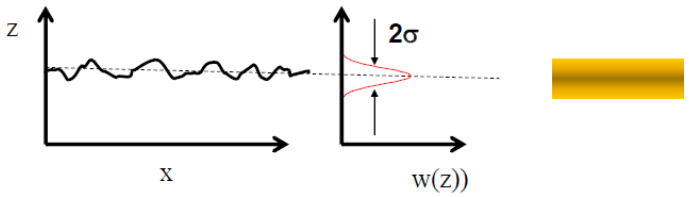
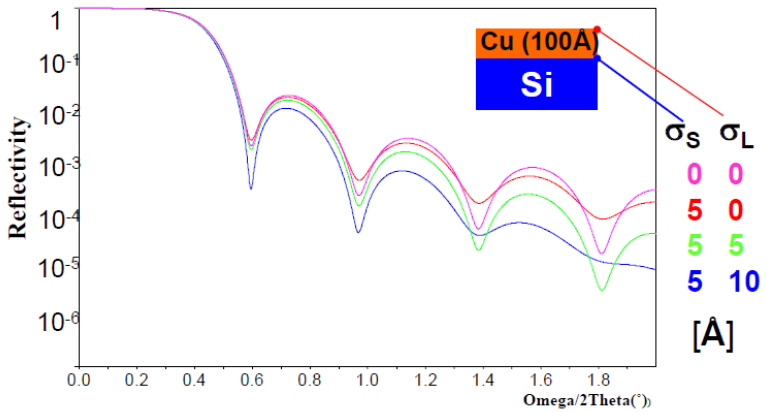
The role of roughness



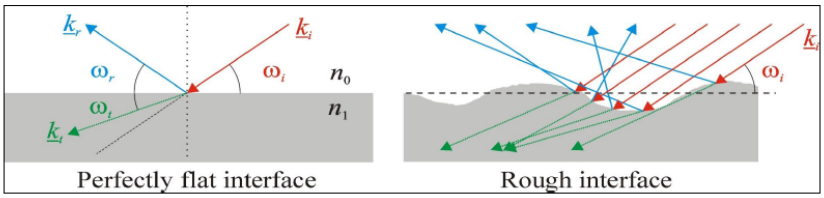
$$r_{j-1,j} = \frac{(k_{j-1} - k_j)}{(k_{j-1} + k_j)} e^{-2\pi^2 k_{j-1} k_j \sigma^2_{j-1,j}}$$

(Névot and Croce, 1980)

Effect of roughness



Off specular scattering due to roughness



Specular scattering is coherent

Diffuse scattering is incoherent

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Diffuse scattering

- X-ray scattering which is not specular
- Information about scale of roughness parallel to interface (lateral correlation)
- Particularly useful for multilayers (vertical correlation)
- Use ω scans at fixed 2θ or offset ω/2θ scans or 2θ at fixed ω
- Or use 2-axes scans

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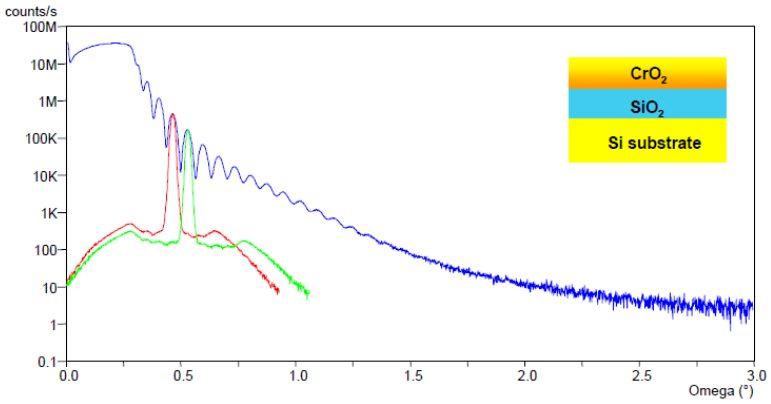
Experimental confirmation of roughness



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Provided sample information

Sample	Sample structure (nm)
#1	Si/Nb(40)/Co(2.5)/Si cap
#2	Si/Nb(150)/Co(10)/Nb(150)/Si cap
#3	Si/Nb(50)/Co(1.5)/Nb(8)/Co(2.5)/Nb(8)/Si cap
#4	Si/Nb(150)/Co(4)/Nb(150)/Si cap

What can we expect from a XRR analysis?

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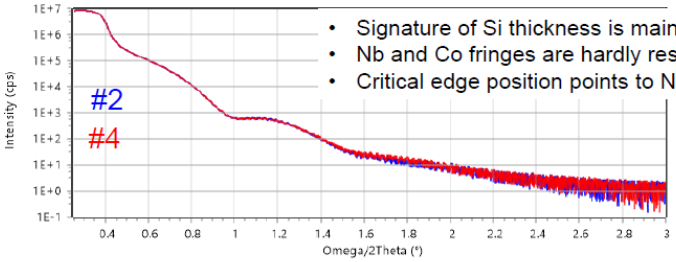
Simulations sample #2 and #4



- Signature of Si thickness is main feature
- Nb and Co fringes are hardly resolved
- Critical edge position points to Nb/Co

#4

#	Layer No.	Type	Material	Density (g/cm³)	Thickness (nm)	Roughness (nm)
▸	4	Single	Si [Diamond]	2.328	7.0	1.0
	3	Single	Nb [DensityOnly]	8.57	150.0	1.0
	2	Single	Co [DensityOnly]	8.9	4.0	0.5
	1	Single	Nb [DensityOnly]	8.57	150.0	0.5
	Sub.	Substrate	Si [Diamond]	2.328	600000.0	0.5

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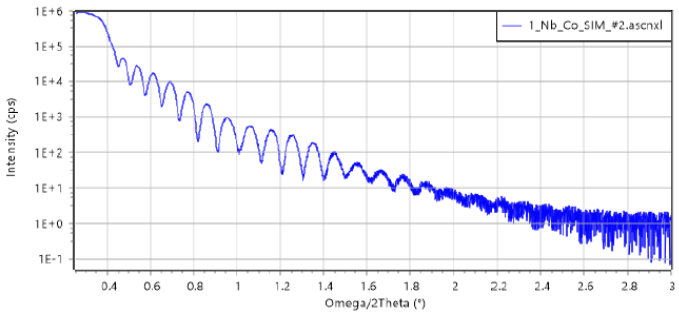
Simulation sample #1

- Beating feature from Si thickness
- Fringe pattern from sum of Nb and Co



#	Layer No.	Type	Material	Density (g/cm³)	Thickness (nm)	Roughness (nm)
▸	3	Single	Si [Diamond]	2.328	8.0	1.0
	2	Single	Co [DensityOnly]	8.9	2.5	1.0
	1	Single	Nb [DensityOnly]	8.57	40.0	0.5
	Sub.	Substrate	Si [Diamond]	2.328	600000.0	0.5

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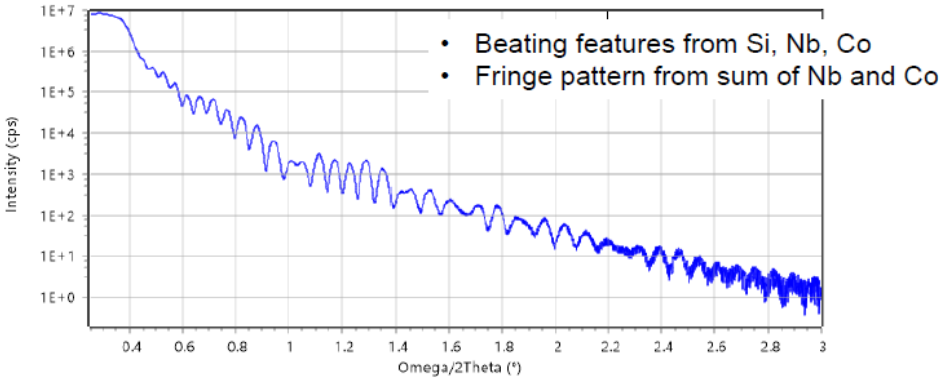
Simulation sample #3



	Layer No.	Type	Material	Density (g/cm³)	Thickness (nm)	Roughness (nm)	Relax (%)
▸	6	Single	Si [Diamond]	2.328	7.0	1.0	0.0
	5	Single	Nb [DensityOnly]	8.57	8.0	1.0	0.0
	4	Single	Co [DensityOnly]	8.9	2.5	0.5	0.0
	3	Single	Nb [DensityOnly]	8.57	8.0	0.5	0.0
	2	Single	Co [DensityOnly]	8.9	1.5	0.5	0.0
	1	Single	Nb [DensityOnly]	8.57	50.0	0.5	0.0
	Sub.	Substrate	Si [Diamond]	2.328	600000.0	0.5	0.0

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Summary

- **X-ray reflectometry**
  - Reliable and fast determination of layer thicknesses and densities
  - Non-destructive, no limitation to sample crystallinity
  - Detection of very thin layers (down to 1 nm)
  - Sample size should be larger than 1x1cm^2
- **Diffuse X-ray scattering**
  - Complementary to XRR
  - Assessment of vertical correlation and in-plane correlation lengths of surfaces and interfaces

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Physics of proximity effect in Superconductor/Ferromagnet structures

Alexander Golubov

University of Twente, The Netherlands

SPINTECH - winter school

Functional nanostructures – modelling, design, characterization

University of Twente, 10-11 February 2022

MESA+ INSTITUTE FOR NANOTECHNOLOGY

SPINTECH

MIPT MOSCOW INSTITUTE OF PHYSICS AND TECHNOLOGY

Univerisity of Twente, the Netherlands

Moscow Institue of Physics and Technology

Laboratory of topological quantum phenomena in superconductors

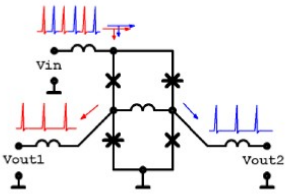
Organized at MIPT by support of Russian government Megagrant in 2014

Unique equipment:

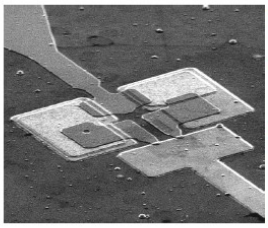
Low temperature high vacuum JT-STM SPECS

Cryogenic system AFM/MFM AttoDRY1000

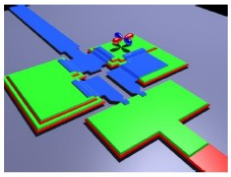
A number of novel superconducting devices using unconventional supercoductors or combinations of Supercodnctors and Ferronagnets have been proposed

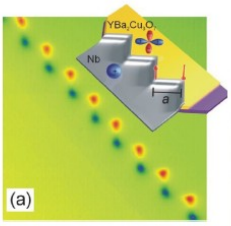


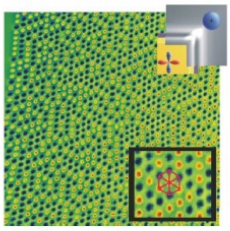
π-junction based T-FlipFlop, without bias lines

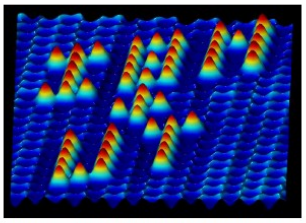


SQUID with build-in ½π phase-shifter (cf. Blatter *et al.*, PRB 2001)









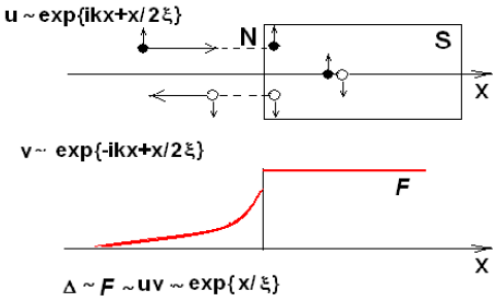
Various array structures with spontaneously generated half-flux quanta

Hilgenkamp, Ariando, Smilde, Blank, Rijnders, Rogalla, Kirtley & Tsuei, *Nature* 422, 50-53 (2003)

Proximity effect in normal metal - superconductor (NS) structures

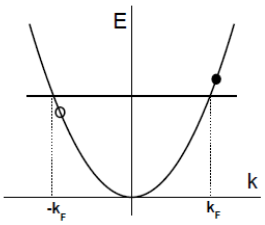
$$\Psi(\vec{r}) = \begin{Bmatrix} u \\ v \end{Bmatrix} = \begin{Bmatrix} u_p \\ v_p \end{Bmatrix} \exp\left\{i\vec{p}\vec{r}\right\} \qquad p^2 = 2m\mu \pm \sqrt{\varepsilon_p^2 - |\Delta|^2}$$

Andreev reflection at SN interface



Proximity effect: Normal and Ferromagnetic metals

N/S

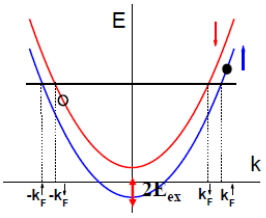


Coherence time of electron and hole $\tau = \frac{\hbar}{2\varepsilon}$

$\xi_N = \frac{\hbar v_F}{2\pi k_B T}$ **ballistic**

$\xi_N = \sqrt{\frac{\hbar D_N}{2\pi k_B T}}$ **diffusive**

F/S

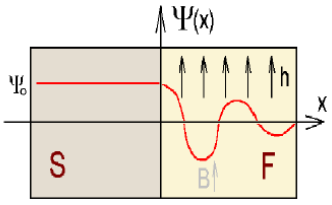


$k_F^{\uparrow} - k_F^{\downarrow} \equiv Q = 2E_{ex}/\hbar v_F$

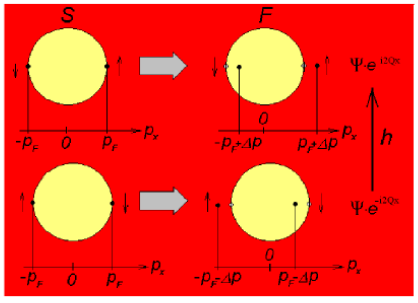
$\xi_F = \frac{\hbar v_F}{E_{ex}}$ **ballistic**

$\xi_F = \sqrt{\frac{\hbar D_F}{E_{ex}}}$ **diffusive**

Spatial oscillations of induced superconducting order parameter in a ferromagnet in proximity to a superconductor



Buzdin & Kupriyanov (1991): analog of the FFLO state

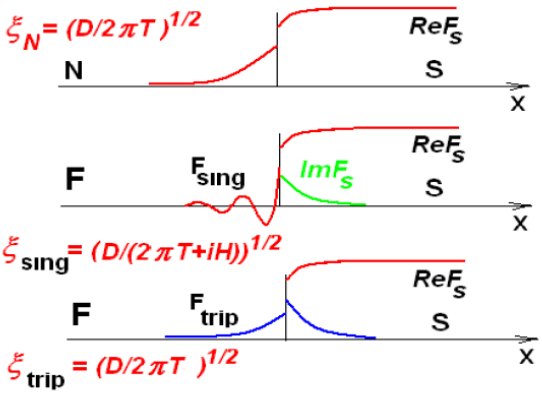


$\Psi(x) = \Psi_0 \cos(2Qx)$

$Q \sim E_{ex}/v_F$ is center of pair mass momentum

Demler, Arnold & Beasley (1997)

Proximity effect: summary



spin singlet
Cooper pair

$\uparrow\downarrow - \downarrow\uparrow$

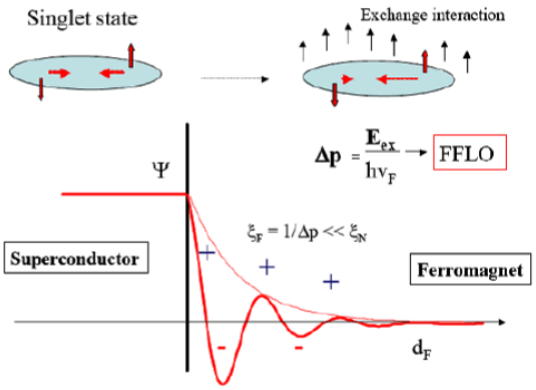
triplet component,
zero-spin projection

$\uparrow\downarrow + \downarrow\uparrow$

equal-spin triplet pairs

$\downarrow\downarrow, \uparrow\uparrow$

Proximity effect in ferromagnetic - superconductor (FS) structures



In the regime $E_{ex} >> kT$ the decay length is given by $\xi_F = \sqrt{\frac{\hbar D_F}{E_{ex}}}$

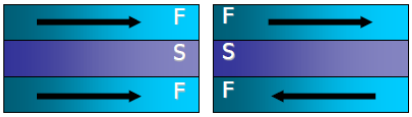
T_c of FSF Trilayers with P and AP Mutual Orientations

"superconducting spin switch"

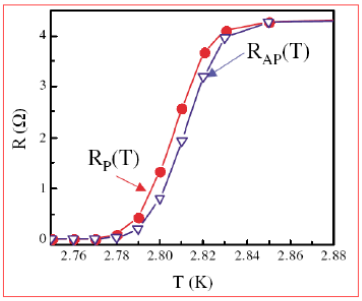
N. Birge et. al. (Michigan State University)

Predicted by Tagirov; Buzdin, Vedyayev, & Ryzhanova (1999).

Observed by Gu *et al.* (2002) using dilute $Cu_{1-x}Ni_x$ alloy in CuNi/Nb/CuNi system



$T_C(P) < T_C(AP)$



$\Delta T_c = T_c^{AP} - T_c^{AP} \approx 6$ mK

Theory of T_c^P vs. T_c^{AP} in F/S/F

Tagirov, PRL 83, 2058 (1999); Physica C **307**,145 (1998)

Baladie & Buzdin, Phys. Rev. B 67 014523 (2003)

Fominov, Golubov & Kupriyanov, JETP Lett. 77, 510 (2003)

You *et al.*, Phys. Rev. B 70, 014505 (2004)

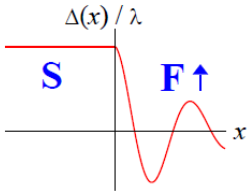
strong ferromagnets $n^{\uparrow}(E_F) \neq n^{\downarrow}(E_F)$

$v_F^{\uparrow} \neq v_F^{\downarrow}$

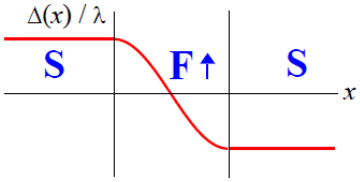
‘0’ and ‘π’ Josephson junctions

$$0 \text{ junction}: \quad I = I_C \sin\varphi, \qquad I_C > 0$$

$$\pi \text{ junction}: \quad I = -I_C \sin\varphi = I_C \sin(\varphi + \pi)$$



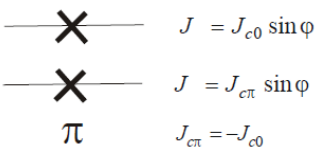
— spatial oscillations of the order parameter in the F layer



— thickness of F layer equals half wave-length of oscillations

Possible applications of π-junctions: novel types of logic elements

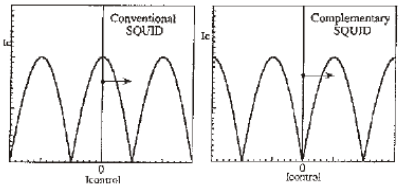
Fundamental equations for ‘0’ and ‘π’ junction



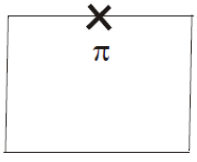
$J = J_{c0} \sin\varphi$

$J = J_{c\pi} \sin\varphi$

$J_{c\pi} = -J_{c0}$



Bulaevskii et al (1977):
Possibility of spontaneous flux in the loop



$$J = \sqrt{J_{c0}^2 + J_{c\pi}^2 + 4J_{c0}J_{c\pi}\cos^2\frac{\pi\Phi}{\Phi_0}}$$

Beasley et al (1998), Blatter et al (2000):
proposals for application of π-juncitons in RSFQ and qubit structures

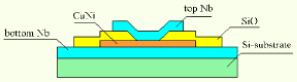
Experimental realization of SFS junctions:

V.Ryazanov *et al.*, Chernogolovka, Russia
J. Aarts, Leiden

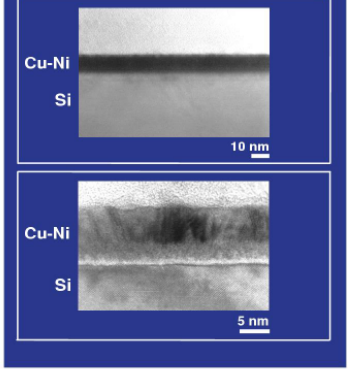
Samples fabrication

- *forming of the bottom Nb strip (width 100 μm) by Nb film dc-magnetron sputtering (110 nm thickness), photolithography and chemical etching*
- *Nb - surface ion etching and CuNi alloy film deposition by rf-diode sputtering*
- *forming of SiO-isolation layer (170 nm) with the "window" (50x50) μm by photolithography, thermal evaporation and "lift-off" process*
- *forming of the upper Nb strip (240 nm thickness and 80 μm width) by photolithography, CuNi-alloy surface ion etching, Nb film dc-magnetron sputtering and "lift-off" process*

Sample side view



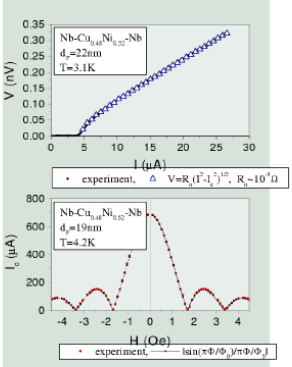
Cross-sectional TEM micrograph of $Cu_{0.43}Ni_{0.57}$ film on Si-substrate



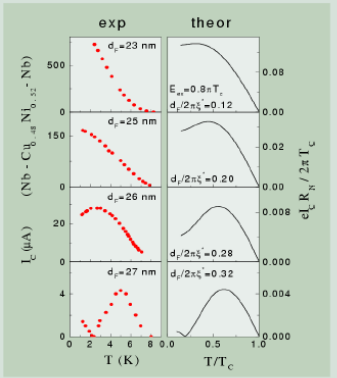
0 - π transition in SFS junctions: theory and experiment

V.Ryazanov, V.Oboznov, A.Rusanov,A.Veretennikov, A.Golubov, and J.Aarts, Phys.Rev.Lett. 86, 2427 (2001)

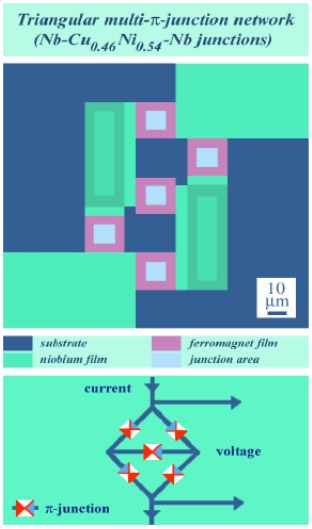
Josephson characteristics for SFS sandwiches

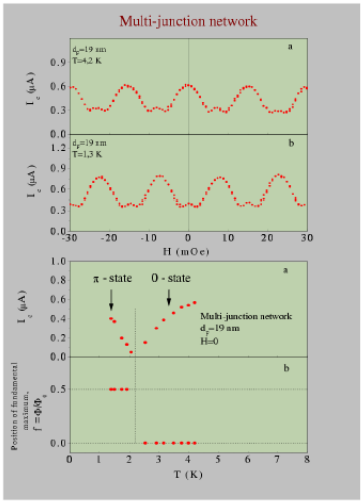


Critical supercurrent vs temperature for different thickness of ferromagnetic layers in SFS sandwiches

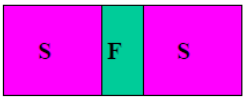


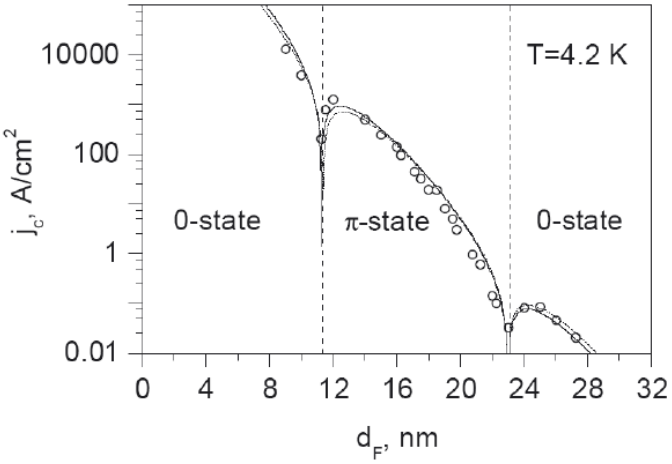
Phase sensitive experiment, Ryazanov *et al (2002)*





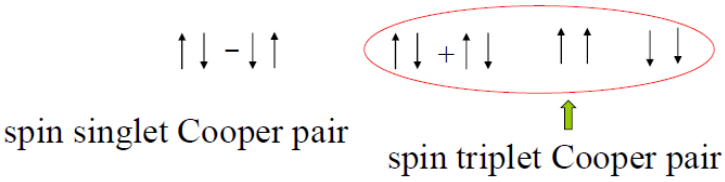
S/F/S π-junctions





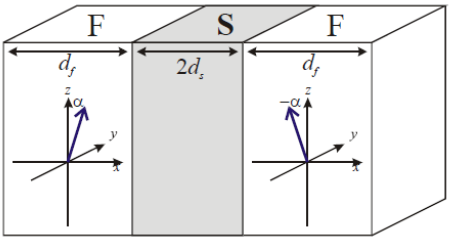
Ryazanov *et al.*, Phys. Rev. Lett. 86, 2427 (2001)
Oboznov *et al.*, Phys. Rev. Lett. 96, 197003 (2006)

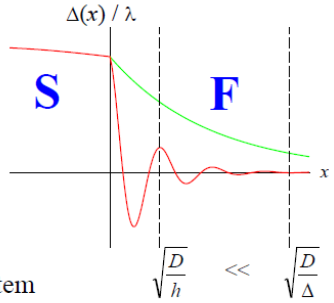
Spin-triplet Cooper pairs are induced in ferromagnet junctions



Bergeret, Efetov, Volkov (2001)

Spin triplet Cooper pairs in SF systems



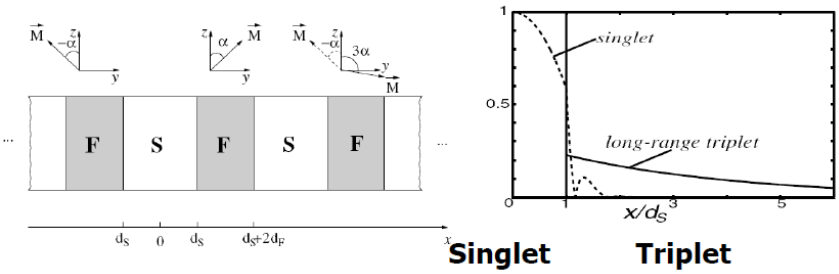


triplet Josephson effect in SF multilayered system
with noncollinear ferromagnets and thin superconductors

Prediction: induced triplet superconductivity in F/S/F with noncollinear magnetizations

Volkov, Bergeret, & Efetov, PRL 90, 117006 (2003); PRB 68, 064513 (2003)

also near a domain wall: Kadrigrobov, Shekhter & Jonson, Europhys. Lett. 54, 394 (2001)



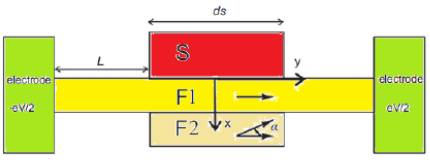
Singlet **Triplet**

Triplet: long-range proximity effect in F:

$$\xi_F^{SC} = \sqrt{\frac{\hbar D_F}{E_{ex}}} \qquad \xi_F^{TC} = \sqrt{\frac{\hbar D_F}{2\pi k_B T}}$$

$$\xi_F^{SC} << \xi_F^{TC}$$

SFF spin valves for control conductivity of F layer.



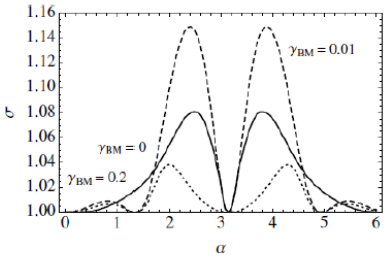
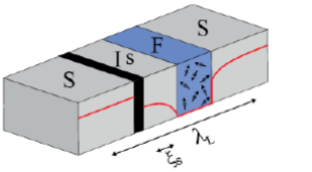
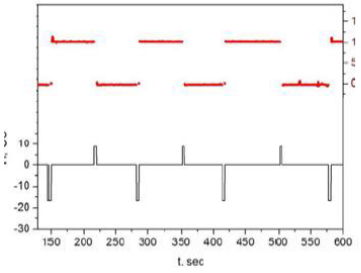


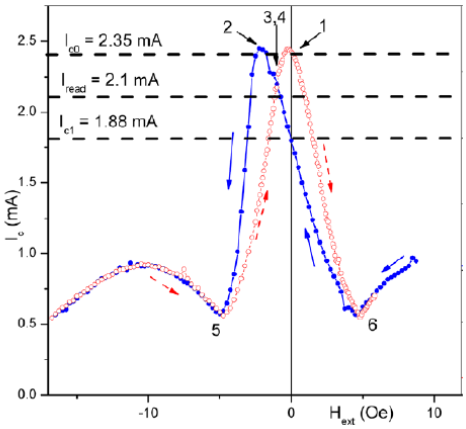
Figure 7: Conductance, σ, vs angle between magnetization vectors, α, for zero voltage at $h_1 = 2$, $h_2 = 5$, $L/\xi_F = 30$, $\gamma_{BS} = 0.4$ for two different suppression parameters $\gamma_{BM} = 0$ (solid line), $\gamma_{BM} = 0.01$ (dashed line) and $\gamma_{BM} = 0.2$ (dotted line).

T Yu Karminskaya et al.,
Supercond. Sci. Technol. 27 (2014) 075008

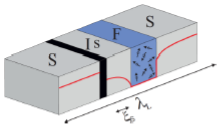
Josephson spin valve devices



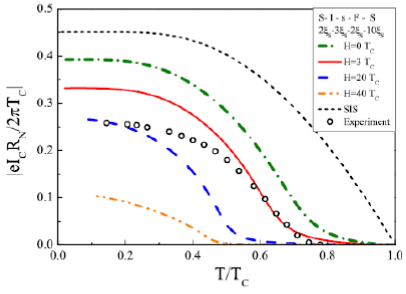


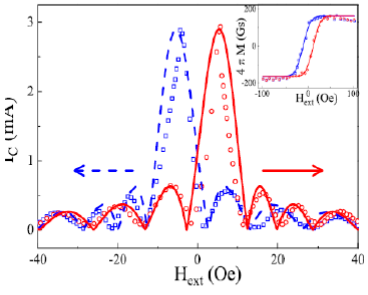


Larkin, T. I., Bol'ginov, V. V., Stolyarov, V. S., Ryazanov, V. V., Vernik, I. V., Tolpygo, S. K., & Mukhanov, O. A. (2012). Ferromagnetic Josephson switching device with high characteristic voltage. *Applied Physics Letters*, *100*(22), 222601.



Josephson SIsFS structure
Theory vs Experiment





Nb-AlOx-Nb-$Fe_{01}Pd_{99}$-Nb

SV Bakurskiy, NV Klenov, II Soloviev, VV Bol'ginov, VV Ryazanov,
IV Vernik, OA Mukhanov, M Yu Kupriyanov, AA Golubov
Applied Physics Letters 102 (19), 192603
Data by ISSP RAS and HYPRES