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

www.elicsir-project.eu

**Twinning Project Days**
**March 24-25, 2021**

SPINTECH

# SPINTECH-project :

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

Prof.Dr. Anatolie Sidorenko, coordinator of the project

IIEN

UNIVERSITY OF TWENTE.

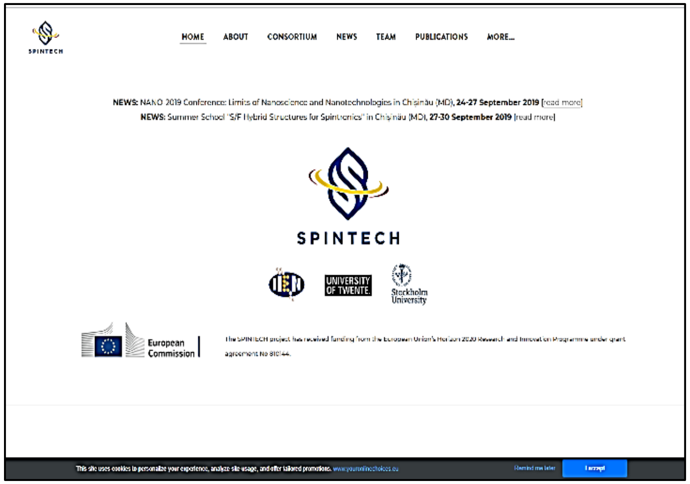
Stockholm University

# Goals of the project

- The overall aim of the SPINTECH project is to boost 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,

in tight collaboration with high-experienced partners: Stockholm University (Sweden) and University of Twente (The Netherlands).

SPINTECH website homepage:



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

**Valdimir Krasnov**
Stockholm, Sweden

**Alexander Golubov,**
**Twente, NL**

**Mikhail Kupriyanov,**
Moscow, Russia

**Vasily Stolyarov,**
MIPT, Dolgoprudny, Russia

**Bernhard Keimer,**
Stuttgart, Germany


**Alexander Vakhrushev**
Izhevsk, Russia

**Lenar Tagirov**
Kazan, Russia

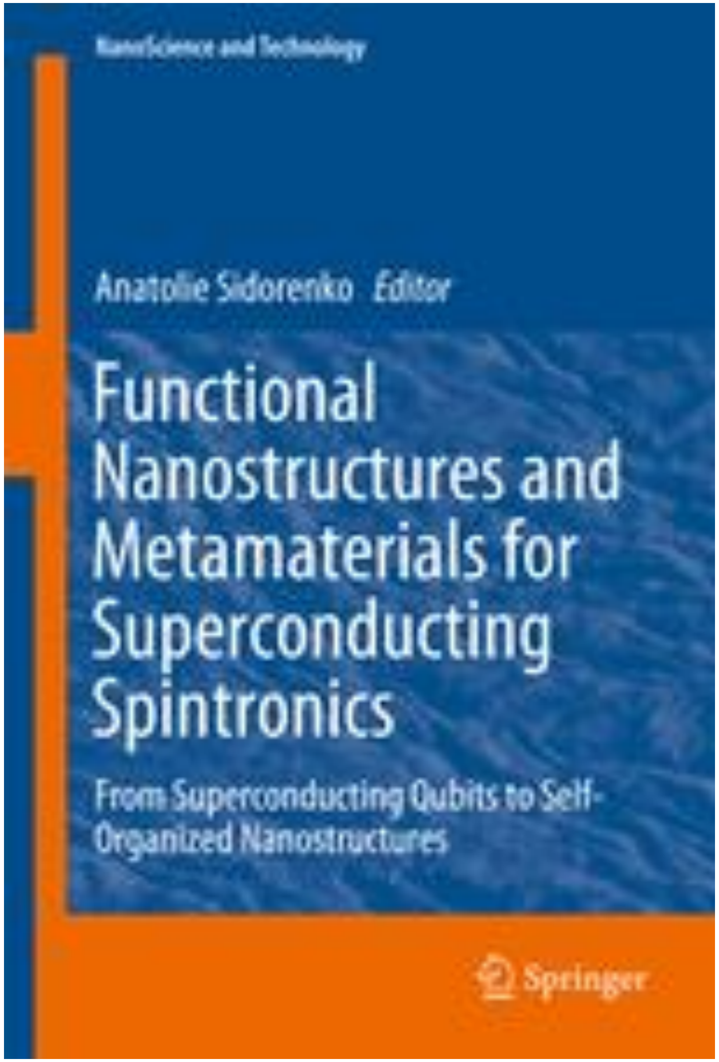
**Horst Hahn**
Karlsruhe, Germany

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

# State of the art

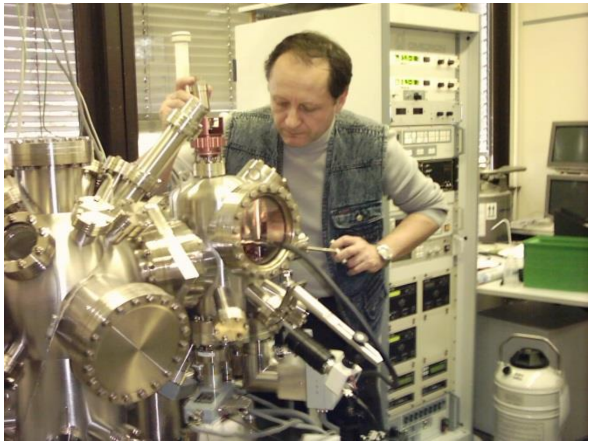
As the base of the project serves : Functional Nanostructures and Metamaterials for Superconducting Spintronics. Ed. by A.Sidorenko,“Springer”, 2018, 270p.

- are summarized results of theoretical and experimental investigation of nanostructures Superconductor/Ferromagnet, novel technologies of their fabrication and characterization.



# Cryogenic laboratory of IEEN, Chisinau, Moldova

- The project is carried out by the **Cryogenic laboratory of IEEN**, which accumulated long – term experience in:
- - Development of different vacuum technologies for fabrication of superconducting compounds, and superconductor/ferromagnet nanostructures, using MBE, DC and RF magnetron sputtering.
- - Experimental research and detection of new phenomena: re-entrant and multiband superconductivity, triplet pairing and triplet spin-valve effect in layered nanostructures;
- - Development of electronic devices – superconducting spin valve for spintronics, based on new detected phenomena.

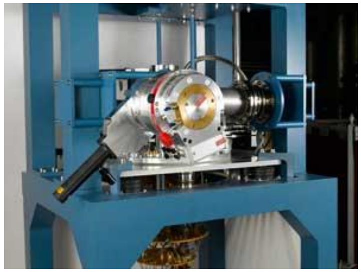


# Partners of the SPINTECH project

- Project progress in tight collaboration with partners:

University of Twente (The Netherlands), and Stockholm University (Sweden) - they are highly experienced in:

- theoretical prediction and calculation of new phenomena in superconductors, theoretical basis of superconducting spintronics, and SQUID-microscopy of S/F nanostructures (A. Golubov, UTWENTE):



- nanolithography and characterization of nanostructures , experimental investigation of superconducting properties (V. Krasnov, SU):

## To achieve the aims of the project during the 3 years of its realization, the partners implement a research and innovation strategy with the following 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 .

# Work packages of the project

the consortium partners put into practice set of **measures** via the project's work packages, which include :

**(i) short term staff exchanges** (WP1);

(ii) **training workshops, conferences and summer schools** (WP2);

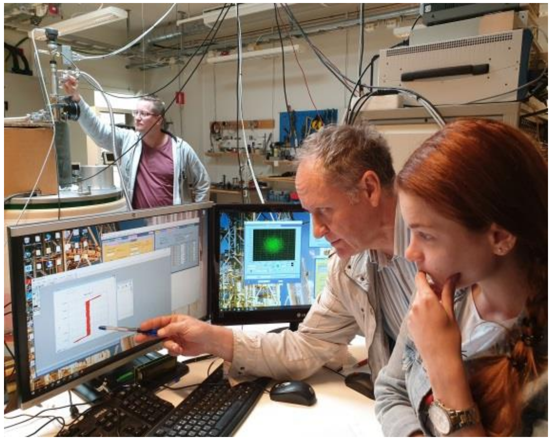
(iii) **dissemination and outreach activities** (WP3).

# Work packages implementation

During 2018-2020 the following  activities were done:

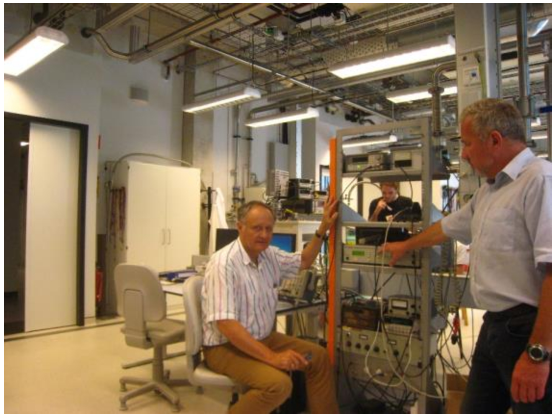
**(i) short term staff exchanges** (WP1) -  8 members of IEEN visited UTwente and UStockholm for up to 4 months work ; 4 members of UStockholm visited IEEN;

3 members of UTwente visited IEEN.



In Uni-Stockholm

in IEEN, Chisinau



in Uni-Twente

# Work packages implementation

## trainings, conferences and summer schools (WP2)

– 4 trainings were organized in IEEN, 2 in UTwente and 1 in UStockholm ;

2 Summer schools:

Second in TWENTE, August 2020:

First in Chisinau, September2019:


European Commission | SPINTECH | MESA+ INSTITUTE FOR NANOTECHNOLOGY

Hybrid Structures for Spintronics and Qubits

*SPINTECH summer school-2020,*

University of Twente, the Netherlands, 01-03 October 2020

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

The central goal of the SPINTECH summer school - 2020 is to bring together leading experts to share their expertise and experience in developing of new ideas and principles in superconducting electronics and spintronics, focussing on their novel implementations.

The sittings will be informal with a 3 days itinerary of meetings enabling and promoting group discussions and interactions among participants. Participation is possible only by invitation.

List of the lecturers:

Prof.Valerii Vinokur (Argonne, USA), Prof. Alexander Golubov (TWENTE, Netherlands), Prof. Hans Hilgenkamp (TWENTE, Netherlands), Prof. Igor Lukyanchuk (France), Prof. Alexander Brinkman (TWENTE, Netherlands), Prof. Vladimir Krasnov (Sweden), Prof. Matthias Eschrig (Germany), Prof. Yukio Tanaka (Nagoya, Japan), Prof. Shu Suzuki (Nagoya, Japan) Prof. Anatolie Sidorenko (Moldova).

Organizing committee:

Alexander Golubov (University of Twente, Netherlands)

Anatolie Sidorenko (Institute of Electronic Engineering and Nanotechnology, Moldova)

Vladimir Krasnov (Stockholm University, Sweden)

http://nano.asm.md/ SPINTECH-school 2020

C Conference Hall, Chișinău

# Work packages implementation

- **First "SPINTECH conference", September 2019:**

## SPINTECH-NANO-2019: Limits of Nanoscience and Nanotechnologies

NANO-2019
SPINTECH + Humboldt Kolleg
Conference

Alexander von Humboldt Stiftung/Foundation

SPINTECH

Academy of Sciences of Moldova

D. Ghitu Institute of Electronic Engineering and Nanotechnologies

Scientific Library (Institute) "A. Lupan"

Ministry of Education, Culture and Research of Moldova

The event is dedicated to the 250th Birthday of Alexander von Humboldt,
10 year Anniversary of the Eastern European partnership,
and 5 years of The Moldova–European Union Association Agreement

### NANO-2019: Limits of Nanoscience and Nanotechnologies

24-27 September 2019, Chisinau, Moldova
and
SPINTECH Summer school "S/F Hybrid Structures for Spintronics",
27-30 September 2019

*This event is supported by the A.v.Humboldt Foundation and the European Union H2020-WIDESPREAD-05-2017-Twinning project "SPINTECH" under grant agreement Nr. 810144*

**Organizing Committee**

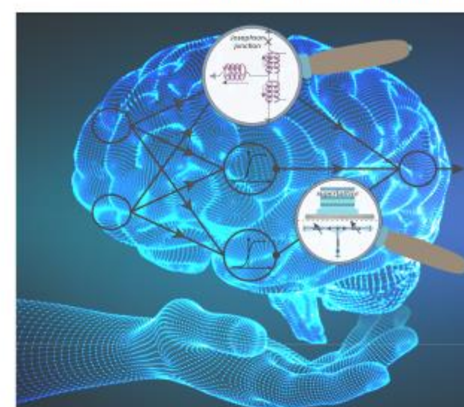
Prof. **Anatolie Sidorenko**, D. GHITU IEEN Chisinau, Moldova
Prof. **Alexander Golubov**, University of Twente, The Netherlands
Prof. **Vladimir Krasnov**, University of Stockholm, Sweden
Prof. **Marian Jaskula**, Jagiellonian University of Krakow, Poland
Prof. **Matthias Eschrig**, Institute of Physics, University of Greifswald, Germany
Prof. **Eugen Sava**, National Museum of Moldova History, Chisinau, Moldova
Dr. **Irina Obukhova**, Moscow Institute of Physics and Technology (Fiztech), Russia
Dr. **Yurii Savva**, I.S. Turgenev Orel State University, Russia
Dr. **Oleg Bujor**, Scientific Library (Institute) "A. Lupan", Chisinau, Moldova

**Best reports, presented at "NANO-2019" conference, are published in the special volume №11 of the Beilstein Journal of Nanotechnology in 2020:**

BEILSTEIN JOURNAL OF NANOTECHNOLOGY

Functional nanostructures for electronics, spintronics and sensors

Edited by Anatolie S. Sidorenko



# Work packages implementation,

## dissemination and outreach activities (WP3):

- **SPINTECH-Newsletter, and Leflet – 2019**
- **Outreach meeting in the mathemathical Gymnasium N37 of Chisinau city 5th March 2019**
- **Day of Open Doors In IEEN, 11th November 2019**
- **“Hakaton-COVID-19”, 24th April 2020**



SPINTECH

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

Newsletter No.1
Sep 2018 - Apr 2019
www.h2020-spintech.eu

**Staff Exchanges**

Staff exchanges, especially those involving early stage researchers, represent the core of SPINTECH activities. In the period between September 2018 and April 2019 more than 8 months of staff exchanges have already taken place. Most of the exchanges involved younger researchers visiting the Twinning partners in Stockholm and Twente, where they learned about advanced lithography technology and SQUID microscopy respectively.

Dr. Roman Morari (IEEN) during his stay at the University of Stockholm.

**Workshops, conferences and summer schools**

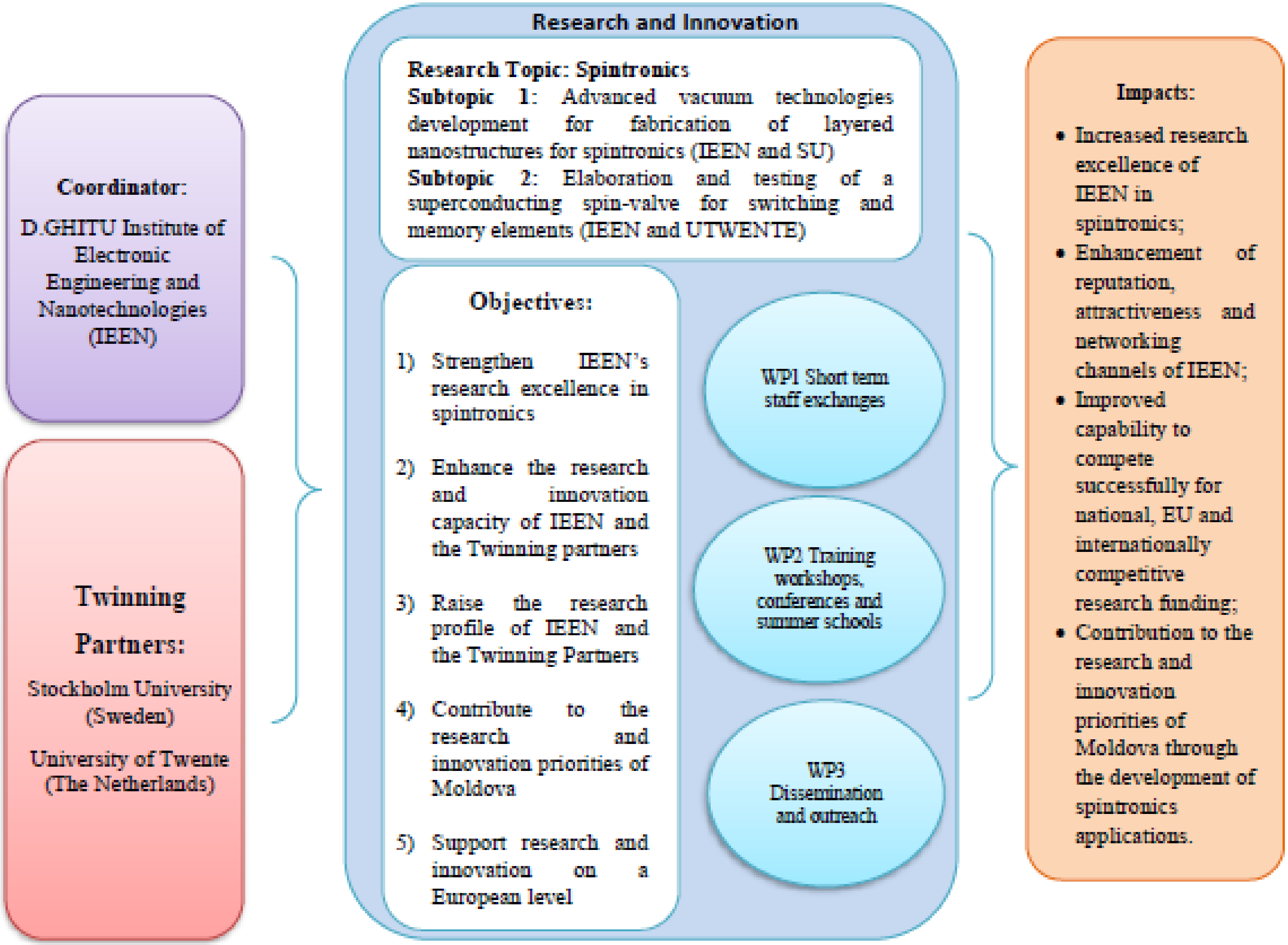
A first workshop, focused on technical issues as well as on opportunities for H2020 support to early stage researchers, was held in Chișinău on March 5th in conjunction with the first periodic project meeting and saw the participation of several members of the advisory board as well as of representatives from MECC. Shortly after, on March 27th, IEEN organized a seminar for its researchers by inviting Dr. N. Klenov from Lomonosov Moscow State University, who presented superconductor-ferromagnet hybrid structures for artificial neural networks. A second technical workshop is expected to take place in Stockholm in June. The consortium partners are currently defining the details of the main events which will take place during the project. According to SPINTECH work plan, 2 international conferences will be hosted in Moldova before the end of the project; the first one, titled "*SPINTECH-NANO-2019: Limits of Nanoscience and Nanotechnologies*", is planned on 24-27 September 2019 in Chișinău and is currently being organized. The second one will be part of the Plasma Workshop series and is expected to take place in the first half of 2021. Finally, with regard to summer schools, the first one will be focused on "S/F Hybrid Structures for Spintronics" and will follow the conference in September 2019. The other two summer schools are expected to take place in Sweden (in 2020) and Twente (in 2021).

M06 project meeting and technical workshop in Chișinău (05.03.2019)

Seminar by Dr. N. Klenov on superconductor-ferromagnet hybrid structures for artificial neural networks in Chișinău (27.03.2019)

European Commission | The SPINTECH project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 810144.

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



# Functional Nanostructures Superconductor/Ferromagnet for Superconducting Spintronics – Smart Technological Approach

**Sidorenko Anatolie**

***Institute of Electronic Engineering and Nanotechnologies, Chisinau, Moldova***

***In collaboration with:***

*University of Twente, Netherlands* **– Alexander Golubov, SPINTECH partner**

*Stockholm University, Sweden* **– Vladimir Krasnov, SPINTECH partner**

**and also:**

*Moscow State University, Russia* **– Mikhail Kupriyanov**

*Institute of Nanotechnology, Karlsruhe, Germany* **- Horst Hahn**

*Max-Planck Institute, Stuttgart –* **Bernhard Keimer**

*Izhevsk State Technical University, Russia* **–Alexander Vakhrushev**

*Kazan State University, Russia* **- Lenar Tagirov**

Topological Quantum Phenomena in Superconducting Systems (MIPT), Dolgoprudny, Russia **- Vasily Stolyarov**

# Motivation of the work:

## Development of the base for non- von Neumann computers

## (brain-like functionality - artificial neural networks)

Control of superconductivity in Superconducting Memory Element

"Brute-force" control of superconductivity in thin films "Cryotron"
– upper critical field which is as high as
~15 kOe ($H_{c\perp}$) for Nb or Ta films ("Cryotron", John Bremer, 1959)

Question: may superconductivity be controlled with a weak magnetic field, 100-1000 times weaker than the critical fields?

Answer: yes, if combined into a heterostructure with a ferromagnetic films !

## Motivation of the work:

# Beasley's Superconducting Memory Element (BSME)

[Applied Physics Letters 71, 2376 (1997)]

### A superconductive magnetoresistive memory element using controlled exchange interaction


Sangjun Oh and D. Youm

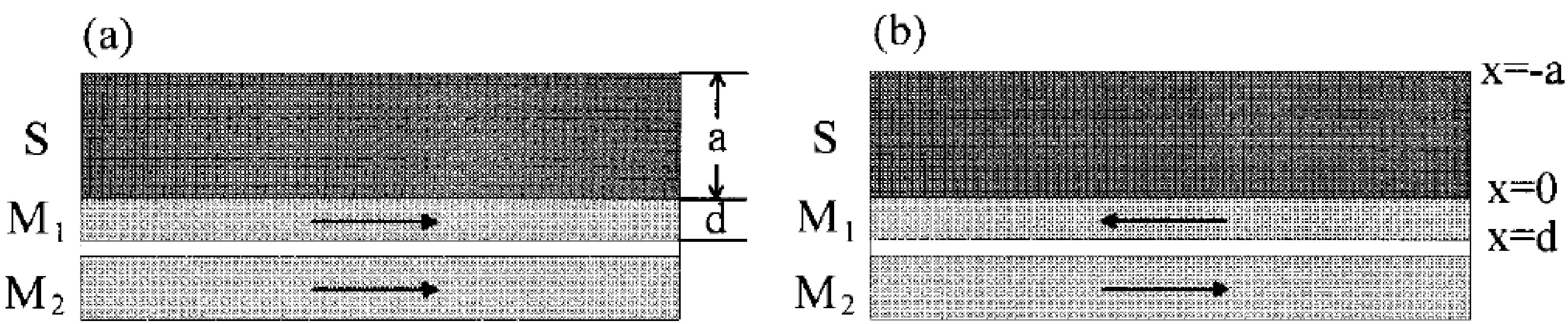
*Department of Physics, Korea Advanced Institute of Science and Technology, Kusung-Dong, Yusung-Gu, Taejon 305-701, Korea*

M. R. Beasley[a)]

*Department of Applied Physics, Stanford University, Via Palou, Stanford, California 94305-4085*

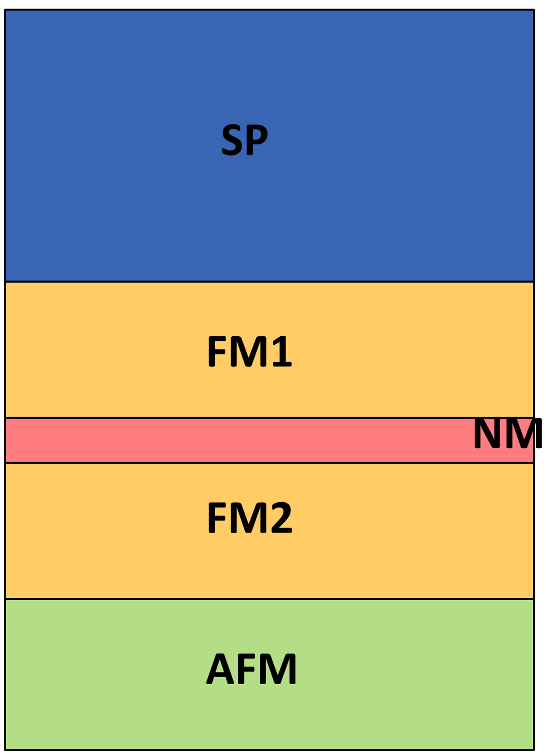


(Received 14 January 1997; accepted for publication 24 July 1997)

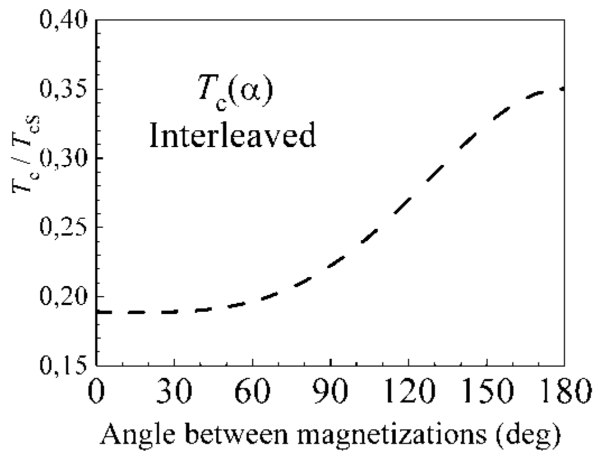



# Two designs of superconducting spin-valves based on the superconductor-ferromagnet proximity effect

Adjacent

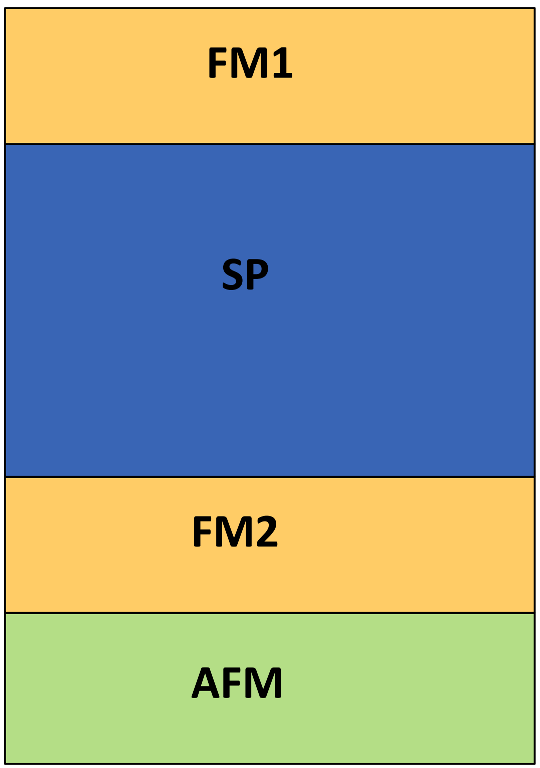



Oh, Youm, Beasley/1997




Alexander Golubov,
Mikhail Kupriyanov
et al.
/JETPL-2003

Interleaved




Lenar Tagirov, Alexander Buzdin et al./19

# Triplet Pairing

**Generation of the triplet components of pairing in superconductor-ferromagnet hybrids (like FSF) at non-collinear magnetic configurations**

$$f_3 \sim \langle \psi_\uparrow \psi_\downarrow \rangle - \langle \psi_\downarrow \psi_\uparrow \rangle,$$

**Even in freq. singlet WF**

$$f_0 \sim \langle \psi_\uparrow \psi_\downarrow \rangle + \langle \psi_\downarrow \psi_\uparrow \rangle,$$

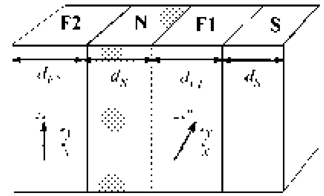
**Even triplet WF with zero projection (*E*ex +AP mag.)**

$$f_1 \sim \langle \psi_\uparrow \psi_\uparrow \rangle \sim \langle \psi_\downarrow \psi_\downarrow \rangle.$$

**Odd triplet WF with ±1 projection (Long-Range, *E*ex +non-coll. mag.)**

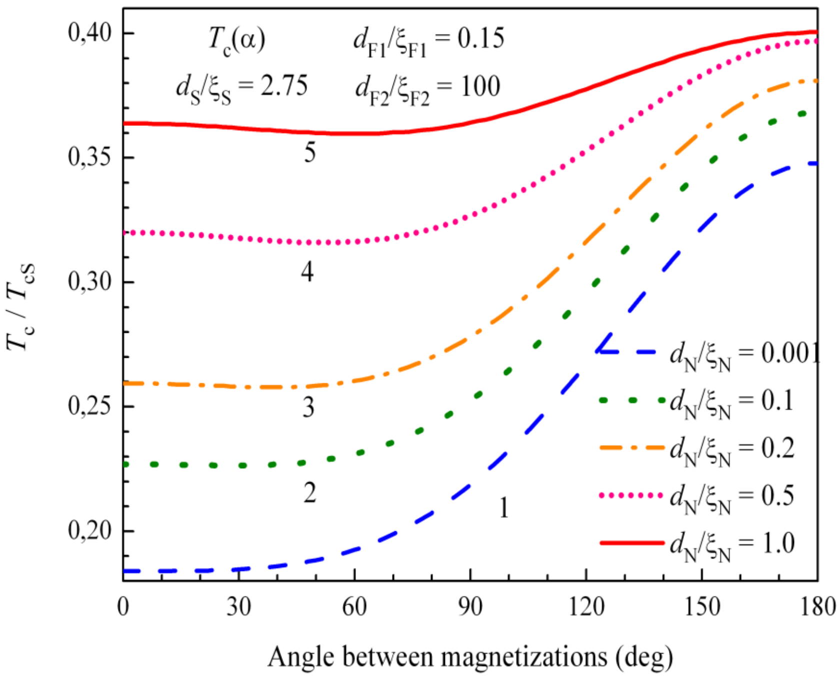

F.S. Bergeret, A.F. Volkov and K.B. Efetov, PRL **86**, 4096 (2001);
A.F. Volkov, F.S. Bergeret and K.B. Efetov, PRL **90**, 117006 (2003);
Alexader Golubov, Mikhail Kupriyanov et al. / JETPL (2003);

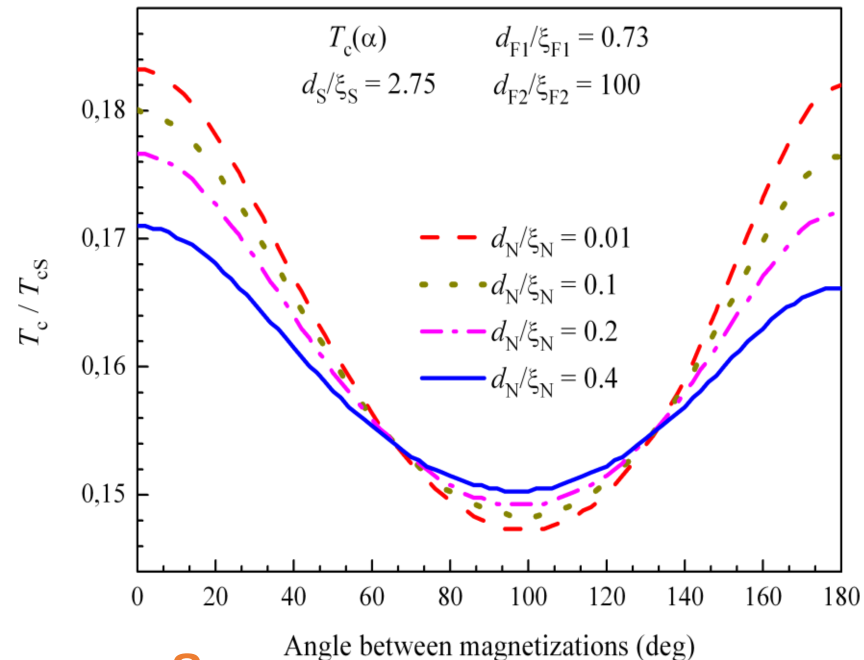
# General model – influence of the norm. metal spacer (N)

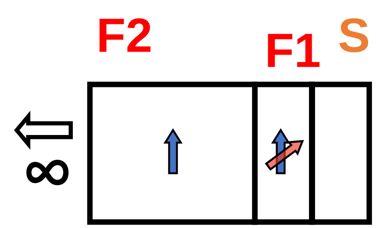



«Direct» switching

«Triplet » switching



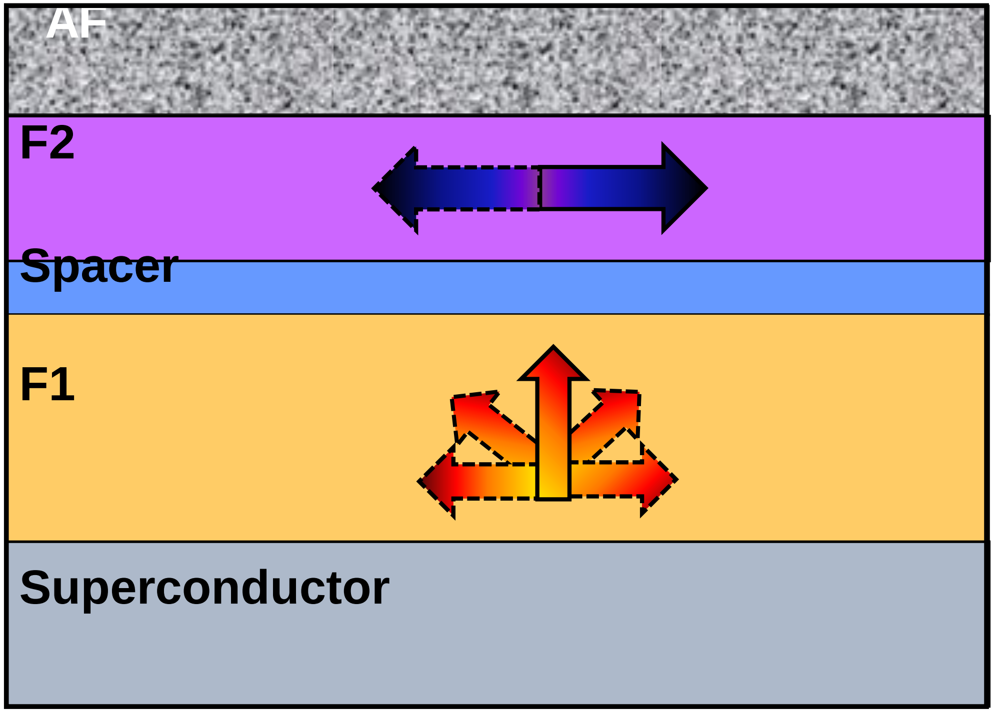




Golubov-Karminskaya-Kupriyanov-Deminov-Tagirov, JETPL 91, 308 (2010)

# The experiment idea and the sample design

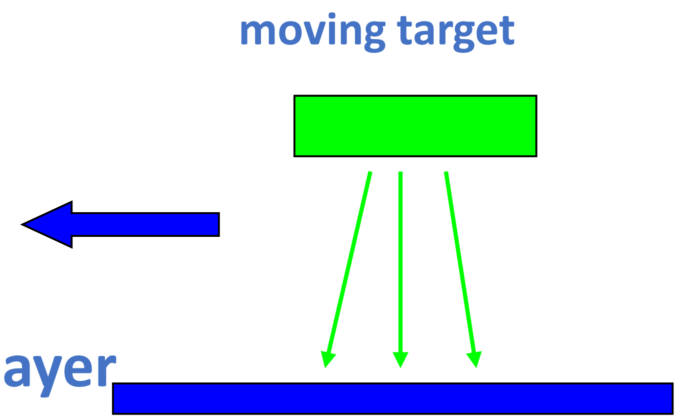
## F1 – soft Perp.Anis. FM, F2 – In-Plane Anis. FM



# Sample preparation- Novel Technology :

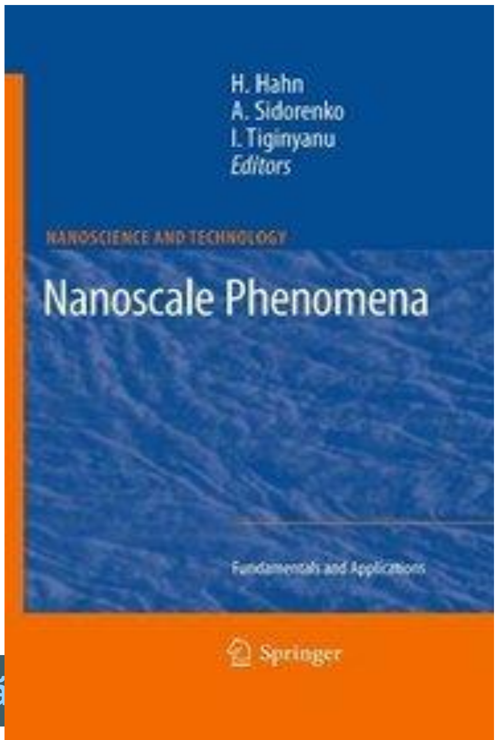
- **DC magnetron sputtering with:**

**a)high deposition rate (4 nm/s)**
**b)moving Nb target**
**c)Deposition of amorphous Si-sublayer**
**d)Protection of the structure with Si-top layer**



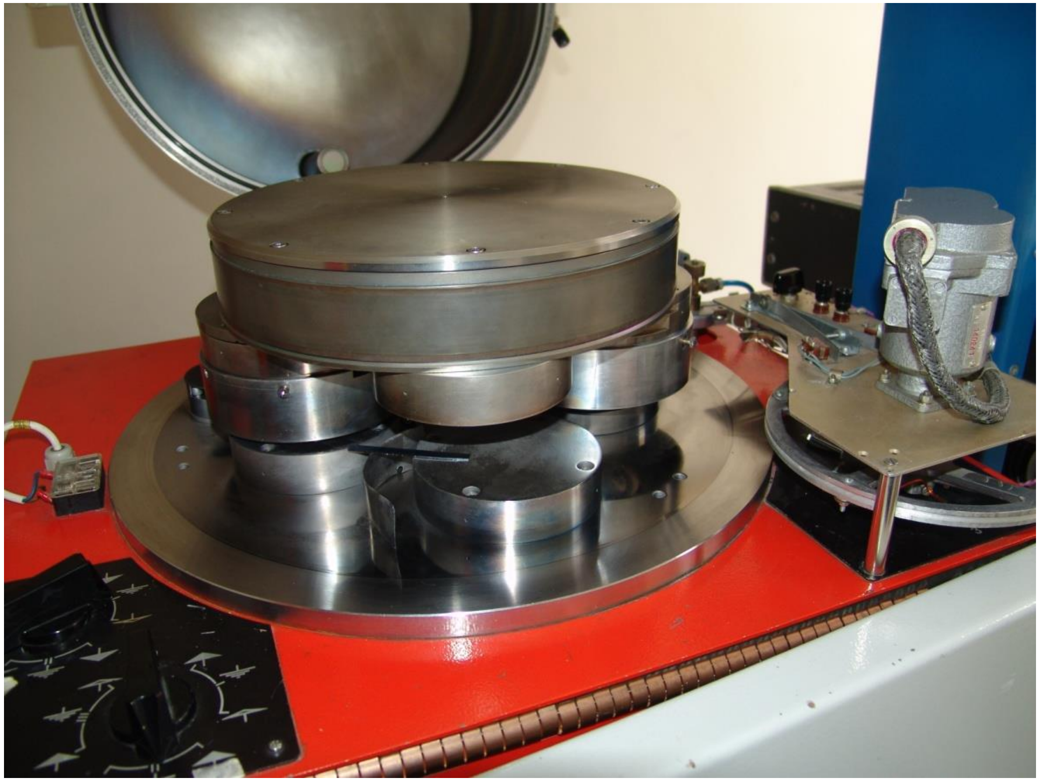

**Detailes of the technology are descriebed in:**

**Nanoscale Phenomena – Fundamentals and Applications.**
**H.Hahn, A.Sidorenko, I.Tiginyanu,**
**Springer, 2009, 237p.**



**SF- samples**

**magnetron sputtering**

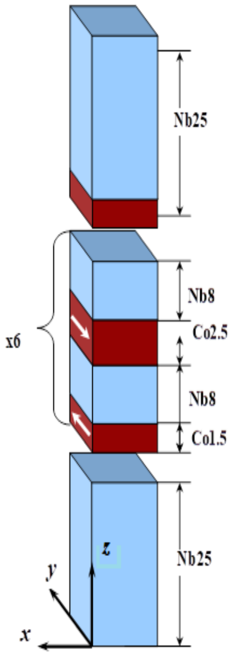


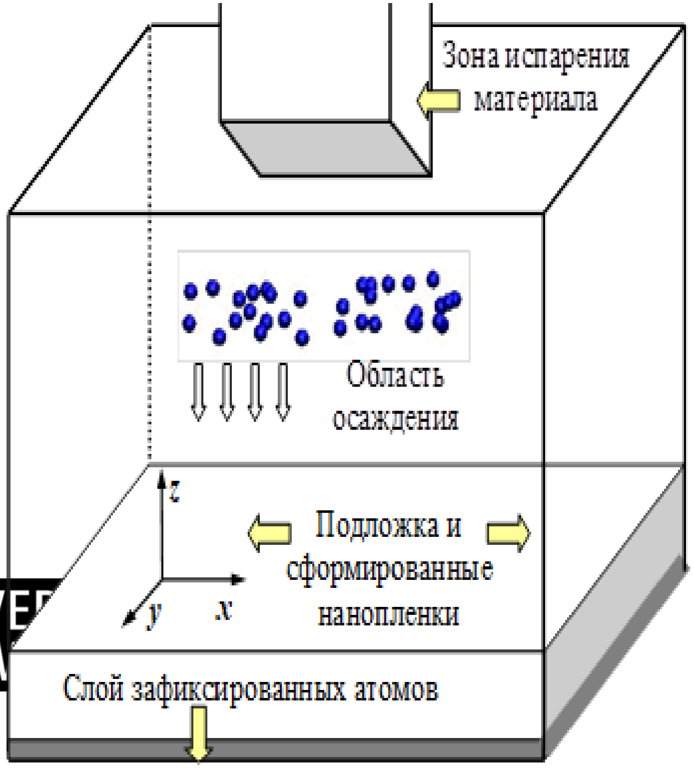
**Technology patented: Patent of RM №3135 from 31.08 2006.**
**Sidorenko A.S., Zdravkov V.I.,**
**“Device for thin films preparation”**

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

# SPINTECH

Modelling of the deposition process for optimization of deposition technology of layers Nb and Co depending on substrate temperature, deposition rate et cet. (model calculations)

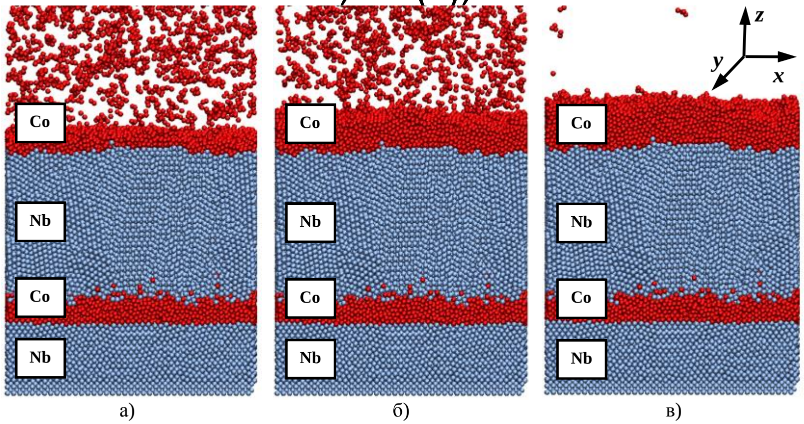


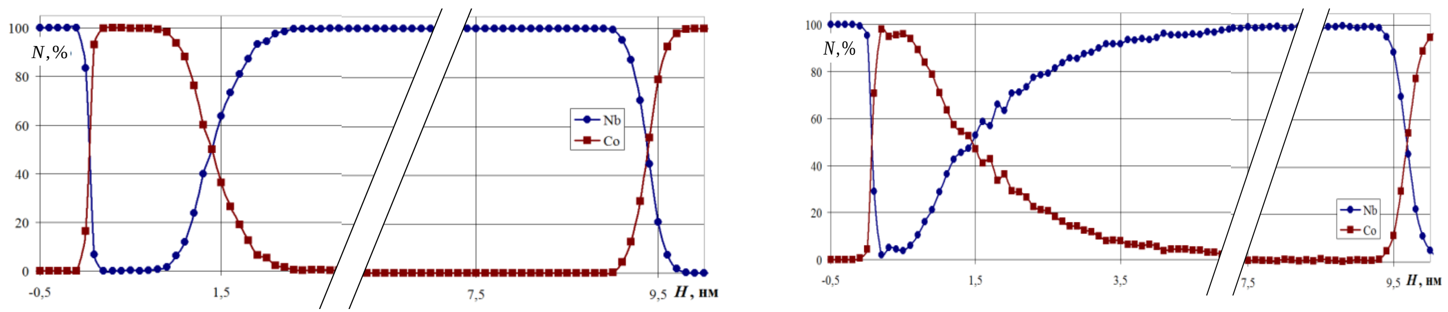
# Model calculations are published in:

## Моделирование процессов формирования сверхпроводящего спинового вентиля на основе многослойной наноструктуры “сверхпроводник/ ферромагнетик”.

ВАХРУШЕВ А.В., ФЕДОТОВ А.Ю., САВВА Ю.Б., СИДОРЕНКО А.С. *Химическая физика и мезоскопия*. 2019, **21** (3), 362-374.

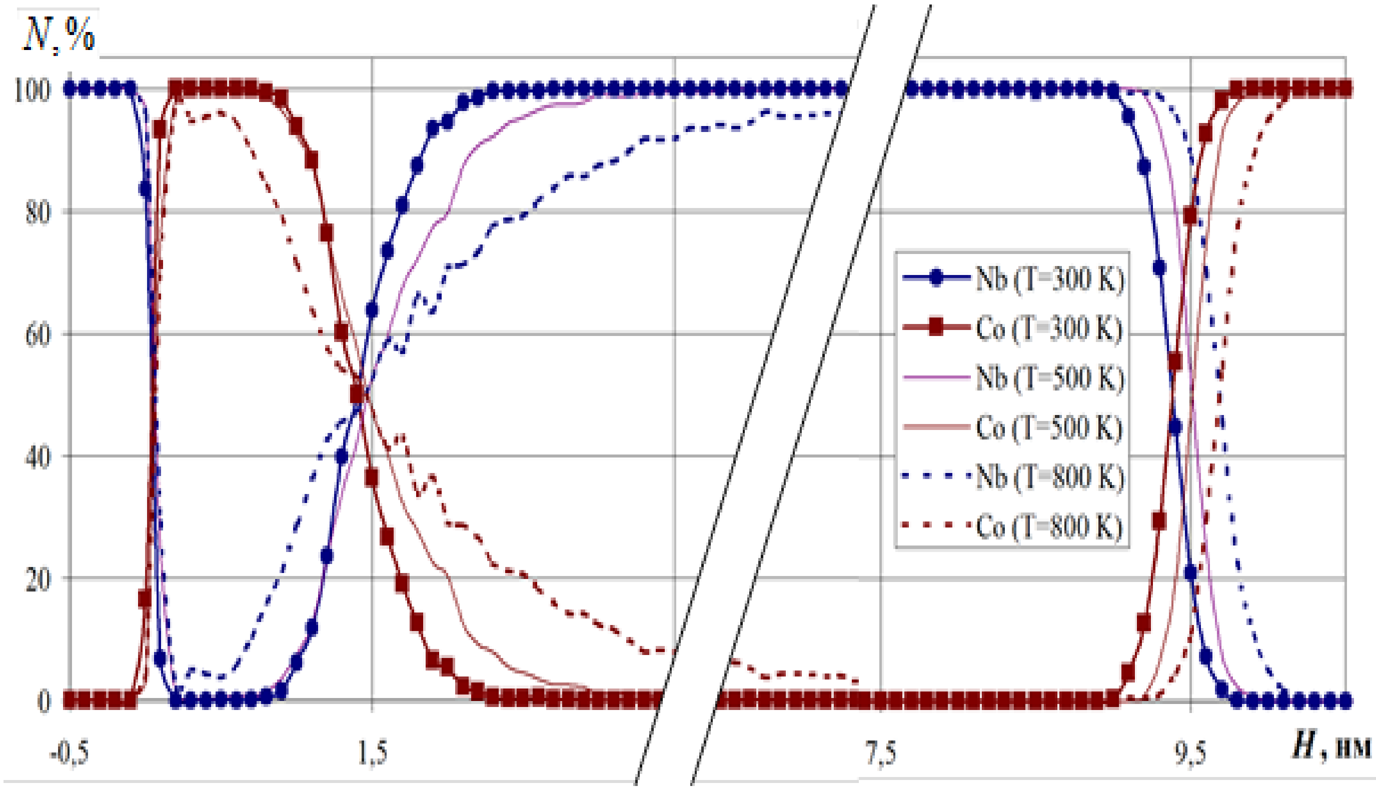



**Condensation of nanolayers Co and Nb at different deposition time: а) 0,1 нс, б) 0,2 нс и в) 0,4 нс. Substrate temperature is fixed at 300 K**
(model calculations)



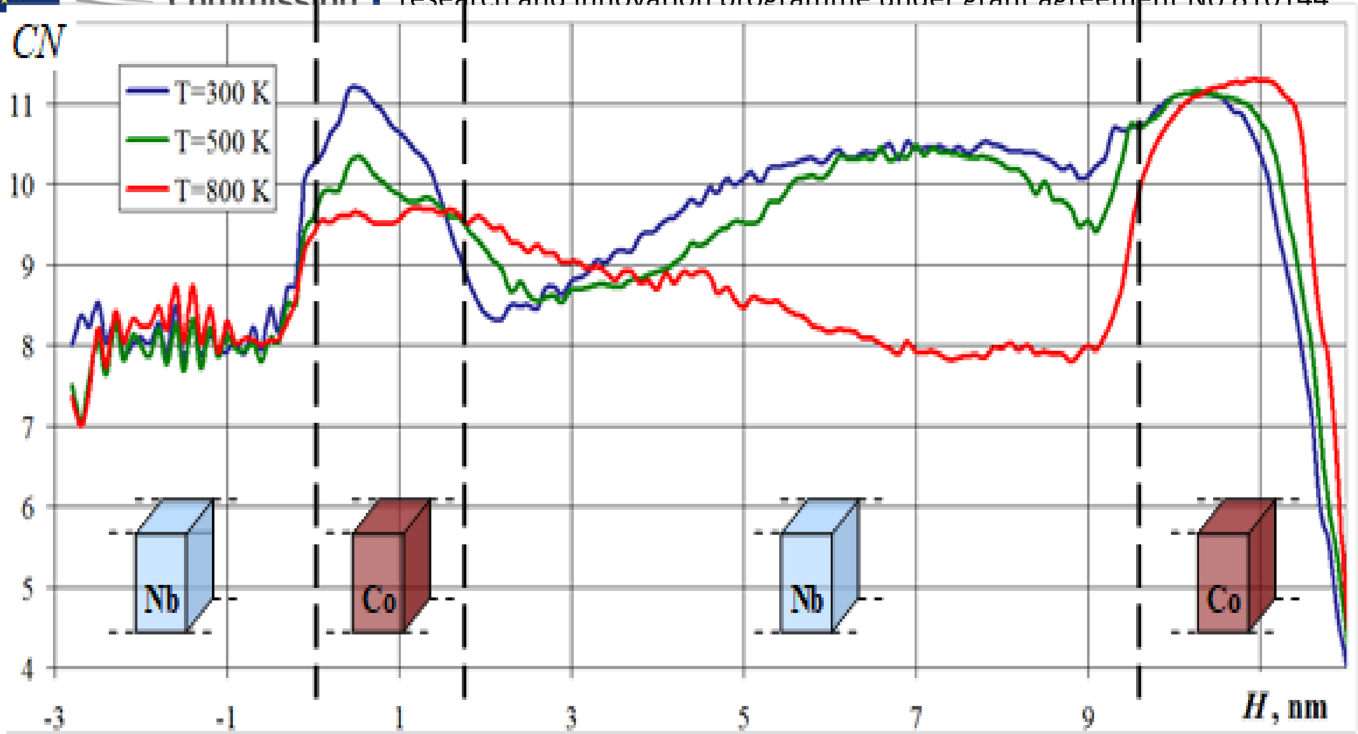

**Composition of the layers Nb and Co, at two different substrate temperatures - 300 K (left) and 800 K (right)**
(model calculations)

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




Composition of the layers Nb and Co depending on substrate temperature (model calculations)

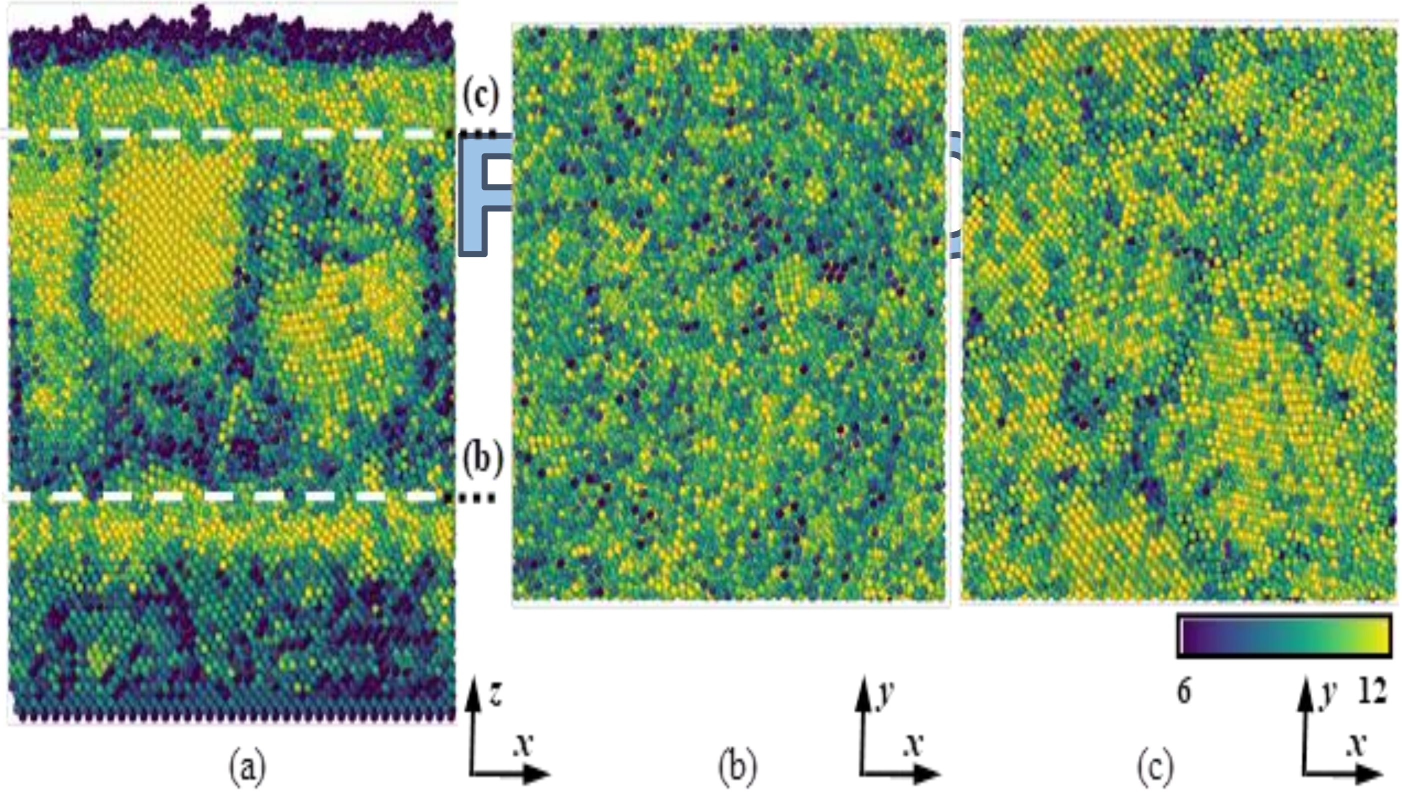
European Commission
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 810144




Changes of the coordination number of Nb and Co in multilayer depending on substrate temperature (model calculations)

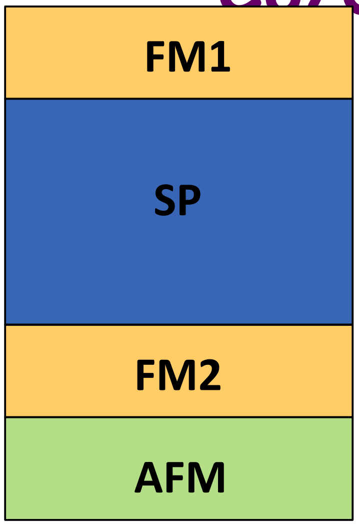
IIEN
UNIVERSITY OF TWENTE.
Stockholm University

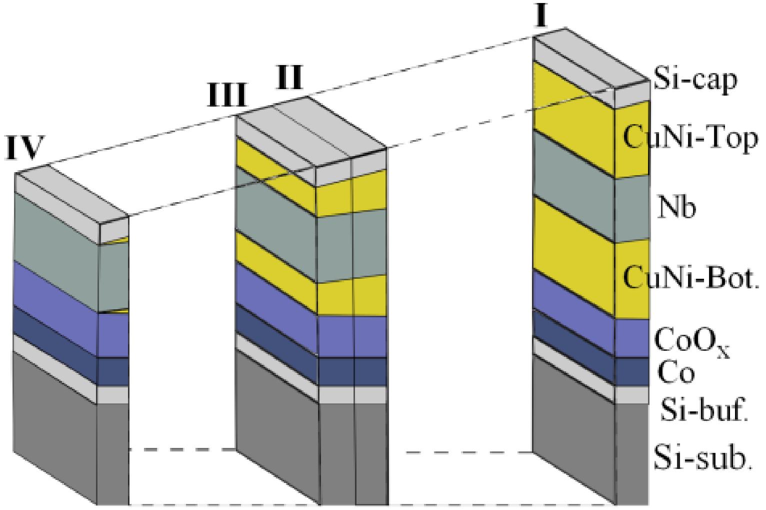
European Commission
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 810144



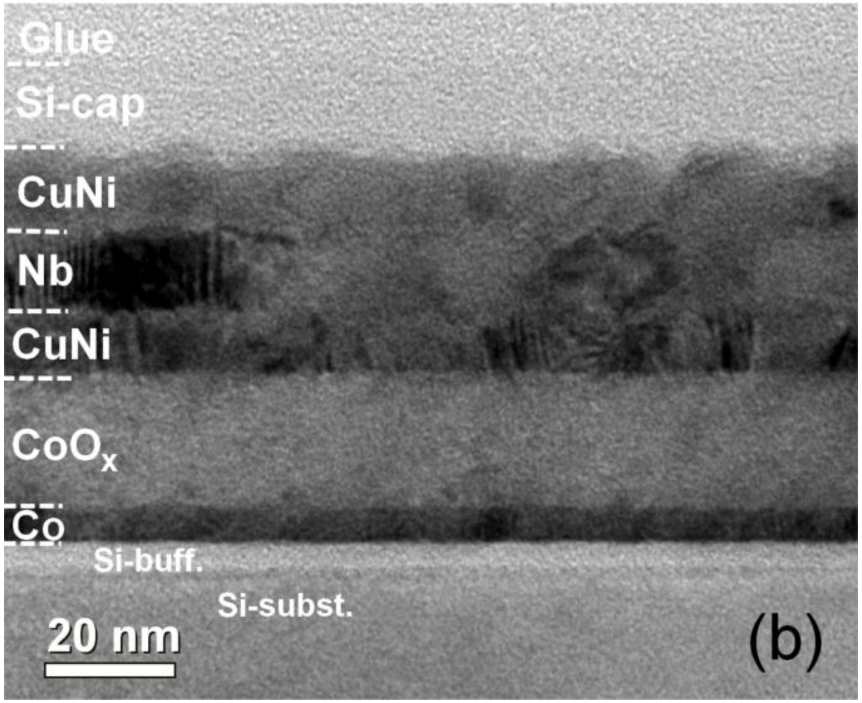

Space distribution ( in planes “c” and “b”) of the coordination number of Nb and Co layers in the Nb/Co multilayer , substrate temperature Ts=300 K (model calculations)

# Spin-valve sample design
# cell core with additional Co layer
# $Co/CoO_x/Cu_{41}Ni_{59}/Nb/Cu_{41}Ni_{59}$



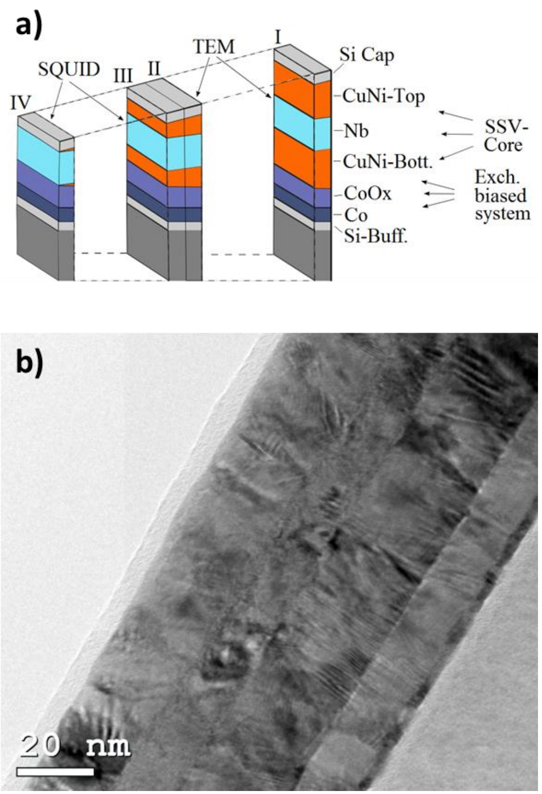




TEM cross-section

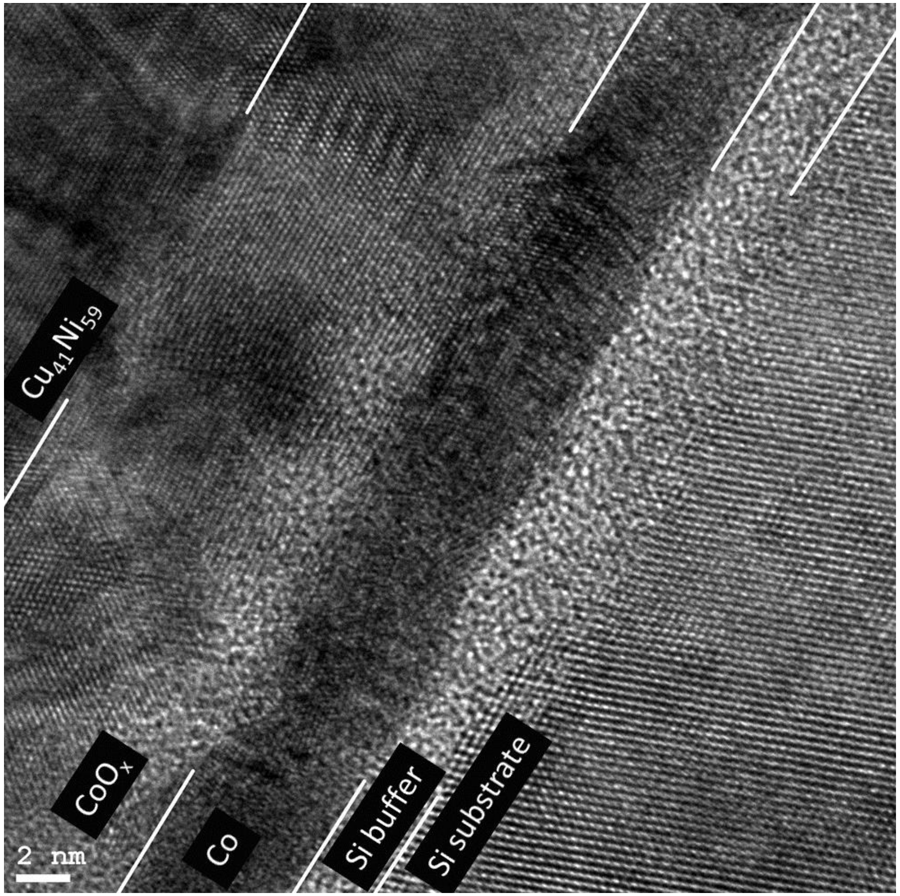



V.I. Zdravkov *et al.*,
APL/2013

# Results of TEM and HRTEM

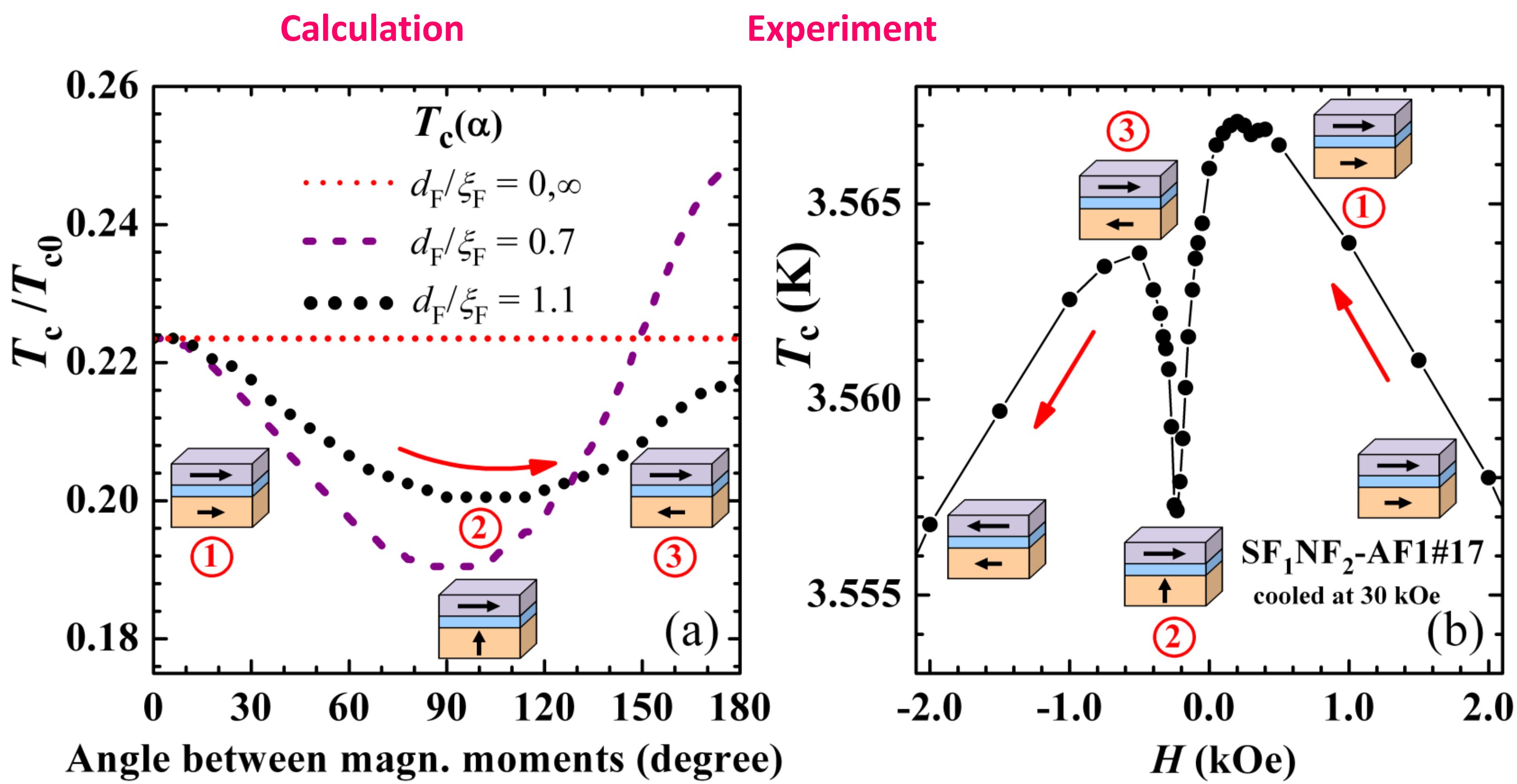



a) Sketch of the samples. b) Cross-sectional TEM of Sample I




Cross-sectional high-resolution TEM image of Sample I at the exchange bias region of the system.

# Dependence of the superconducting transition temperature on mag. field




Phys.Rev.B87, 144507 (2013)

**Experimental Observation of the Triplet Spin-Valve Effect in a Superconductor-Ferromagnet Heterostructure. V.I. Zdravkov, A.S.Sidorenko, L.R.Tagirov et al.**

# Full Switching FSF-type Superconducting Spin-Triplet MRAM-Element

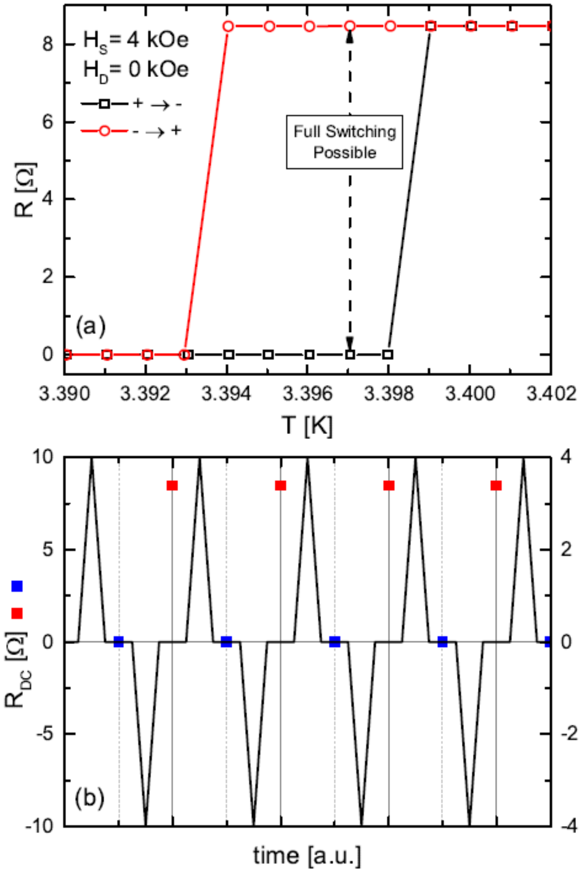



FIG. 8. (a) Superconducting $R(T)$ transition curves measured at zero magnetic field for decreasing and increasing $H_D$ (black and red, respectively). Full switching from the superconducting to the normalconducting state is possible, as indicated *e.g.* at $T = 3.397$ K. (b) Demonstration of the switching between the normal state (red) and the superconducting state (blue) for zero applied magnetic field at $T = 3.397K$. The solid curve illustrates the magnetic field applied for the switching.

***A.Sidorenko, V. Zdravkov, D. Lenk, R. Morari, et al. Full Switching FSF-type Superconducting Spin-Triplet MRAM-Element.***

Phys. Rev. B **96**, 184521 (2017)

# Giant spin-valve effect in Josephson contact with magnetic weak link

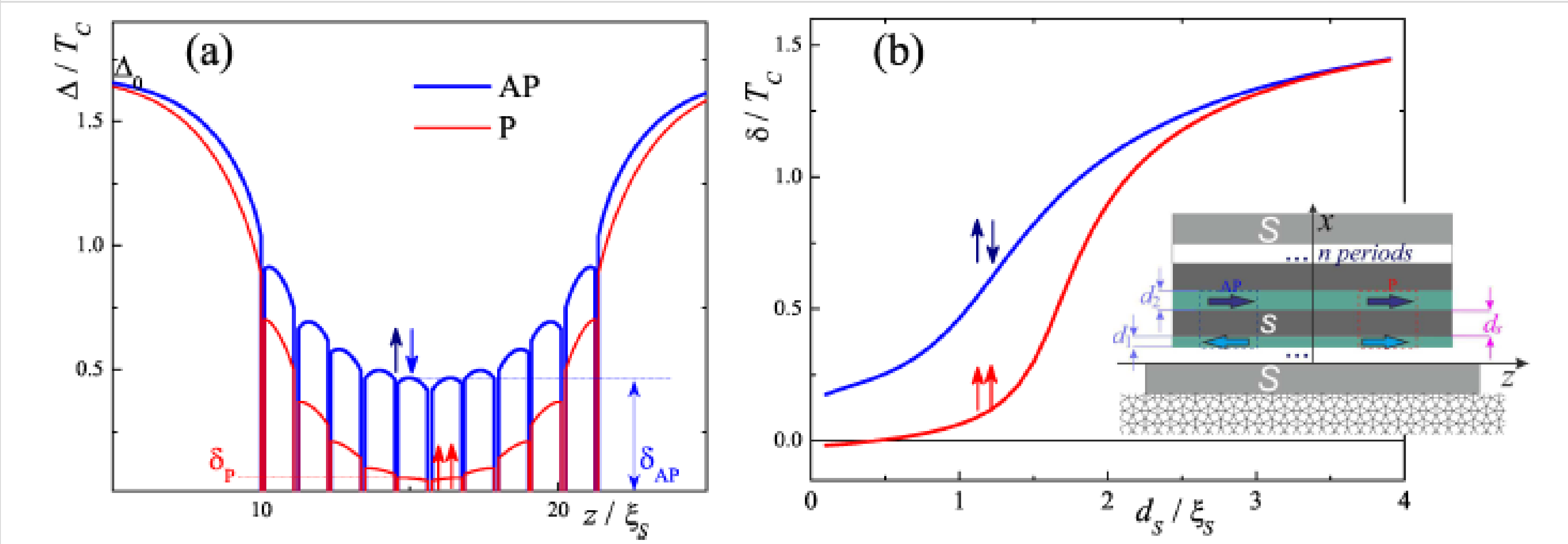
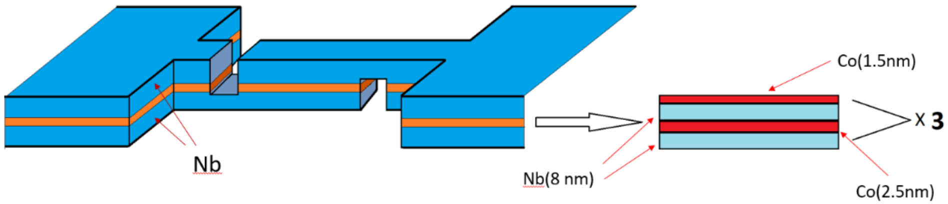
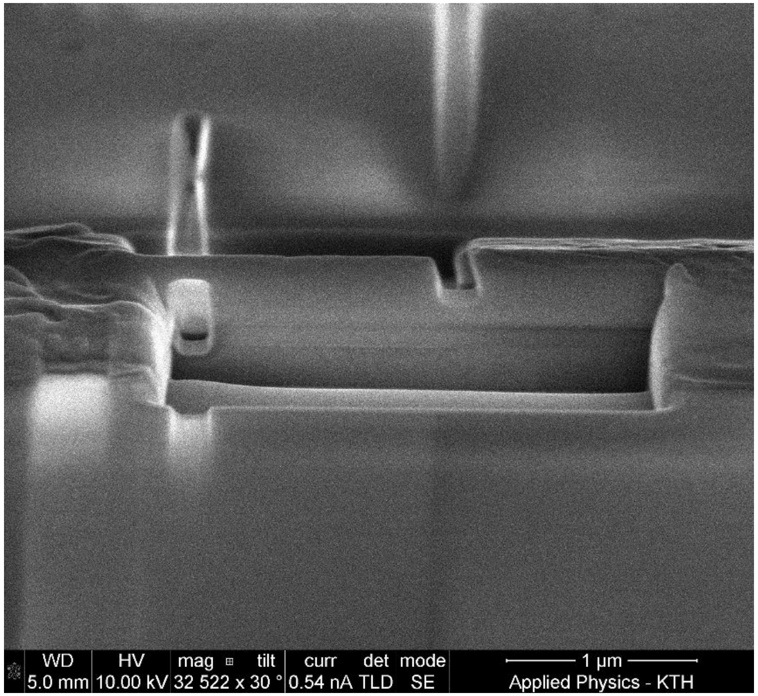



**Figure 2:** (a) The depth profile of the superconducting pair potential amplitude of the $S/[F_1/s/F_2/s]_5/F_1/S$ structure in the P and AP cases. (b) The amplitudes of the superconducting pair potential in the middle of the weak link for the same situations. Inset – schematic representation of the considered stack structure.


N. Klenov, Y. Khaydukov, S. Bakurskiy, R. Morari, I. Soloviev, V. Boian, T. Keller, M. Kupriyanov, A. Sidorenko, B. Keimer, Periodic Co/Nb pseudo spin valve for cryogenic memory, Beilstein J. Nanotechnol. 10 (2019) 833–839. https://doi.org/10.3762/bjnano.10.83.

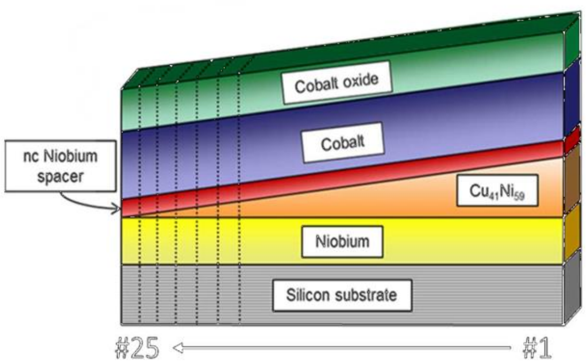
# Fabrication of the Josephson-spin valve using Focused Ion Beam (FIB)-technology

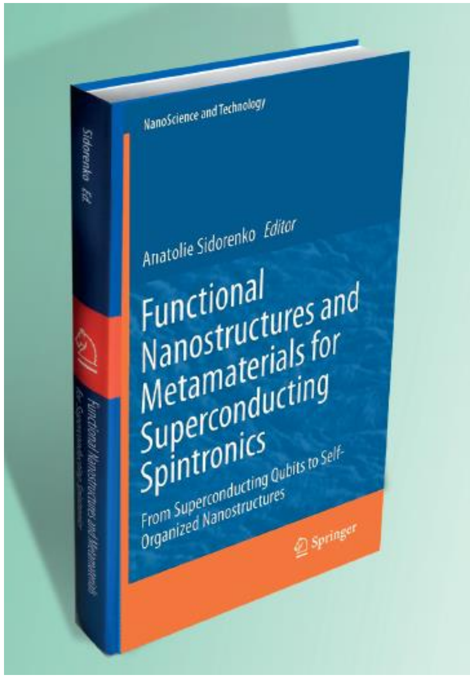


# C O N C L U S I O N

**Elaborated smart technology for S/F hybrid nanostructures fabrication, detected "memory effect" and triplet spin-valve effect, can serve as the base for development of superconducting spintronics and further for non-von Neumann computer design.**



# Second SPINTECH-Conference: 22-25.09.2021

Conference web page:

**http://nanotech.md/ SPINTECH-2021**

Project SPINTECH

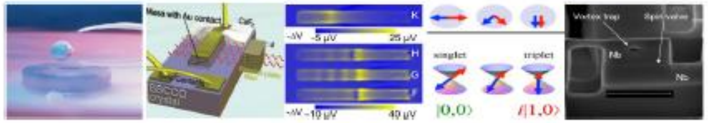
European Commission

SPINTECH

**The 12th International Conference on Intrinsic Josephson Effect and Horizons of Superconducting Spintronics**

*22-25 September 2021, Chisinau, Moldova*

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



The aim of the event is to strengthen regional and interdisciplinary links between the scientists and scholars, while supporting the development of international contacts and introducing young researchers to professional and fruitful scientific work practices. The main goal of the Conference is to bring together leading experts to share their expertise and experience in developing of new ideas and principles, novel technologies and their implementations on frontiers of high-frequency superconducting electronics and spintronics.

**Main topics:**

- **Physics and applications of the intrinsic Josephson effect.**
- **S/F hybrid structures and horizons of superconducting spintronics.**
- **High-frequency Josephson devices**
- **Unconventional and topological superconductivity**

***Conference format***

Due to restrictions related to COVID-19 pandemics, being optimistic, we plan to organize the conference in a mixed format both in physical and virtual space. Physically it will take place in Chisinau, Moldova. Physical participants will get a regular service including coffee breaks and social activity. All presentations will be live-streamed, facilitating virtual participation.

Types of presentations: Oral (invited and regular, either physical or virtual), Poster (virtual only)

***Dates***

Registration starting on January 15, 2021

Deadline for registration and 1-page Abstract Submission: July 1, 2021

Conference dates: September 22-25, 2021

***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).