ESAS WINTER SCHOOL - December 2016 - Pozzuoli (Napoli, Italy)

		Monday 12th	*Tuesday 13th*	*Wednesday 14th*	*Thursday 15th*	*Friday 16th*	Saturday 17th
8:45	9:00	*Welcome*					
9:00	9:30	Mukhanov	Tanaka	Aarts	Mukhanov	Giazotto	Departure
9:30	10:00						
10:00	10:30			Robinson		Sobolewski	
10:30	11:00						
11:00	11:30	*coffee*	*coffee*	*coffee*	*coffee*	*coffee*	
11:30	12:00	Tanaka	Kimel	Boschker	Vernik	Sobolewski	
12:00	12:30						
12:30	13:00					Ortlepp	
13:00	13:30						
13:30	14:30	*lunch*	*lunch*	*lunch*	*lunch*	*lunch*	
14:30	15:00		IEEE CSC Italy Chapter: Della Corte / Silva				
15:00	15:30	Lombardi/ Bauch	Robinson	Aarts	Giazotto	Ortlepp	
15:30	16:00						
16:00	16:30		Aarts	Kimel		*Conclusions*	
16:30	17:00						
17:00	17:30		Robinson	Boschker	Sobolewski		
17:30	18:00						
18:00	18:30		Short presentations participants	Short presentations participants			
20:00			Social Event sponsored by IEEE				

Lecturer: Oleg A. Mukhanov and Igor Vernik (HYPRES , USA)

Title: Superconducting Single Flux Quantum Technology

Abstract: An introduction to superconducting digital electronics will be presented. The lecture will cover superconducting single flux quantum (SFQ) circuits with special attention to RSFQ logic family where digital “1” and “0” are represented by the presence and absence of single quantum of magnetic flux in a superconducting loop. These circuits were demonstrated to be operational at a hundred-GHz clock speed with a low device switching energy of the order of aJ/bit. When combined with a zero-energy ballistic transfer of SFQ pulses over superconducting passive transmission lines, the SFQ-type circuits can demonstrate the higher performance in complex digital and mixed-signal circuits as compared to any other technology. We will present the RSFQ design fundamentals followed by cells and cell libraries together with basic circuits. A typical circuit design flow will show how RSFQ circuits can be designed and optimized. We will also review the integrated circuit fabrication, testing methods, and cryogenic system packaging principles. Various RSFQ circuit for different applications ranging from small-scale cryogenic systems to large-scale computing systems will be reviewed. Finally, we will discuss recent technology trends and development priorities.

Lecture outline:

- *Brief review of superconducting digital electronics development timeline*
- *Basics of Josephson junctions and Single Flux Quantum (SFQ) circuits*
  - Josephson junctions as switching elements
  - Switching speed and energy
  - RSFQ logic fundamentals
- *RSFQ digital circuits*
  - RSFQ design guiding principles
  - RSFQ cells and cell libraries
  - Basic RSFQ circuits
- *Integrated circuit design*
  - Design tool set
  - Typical design flow
  - Examples of circuit design
- *Integrated circuit fabrication*
  - Typical multilayer process
  - Examples of modern fabrication processes and trends
  - LTS vs HTS
  - Multi-chip modules
- *Integrated circuit testing*
  - Test approaches
  - Input/Output (I/O) converters
  - Testing in cryogenic environment
- *Cryogenic system packaging*
  - Typical cryosystem
  - Cryosystem design tradeoffs

    - I/O challenge
    - Cryosystem examples

- *Applications of RSFQ circuits*
    - Digital processing
    - Memory
    - Data converters
    - Sensor readout
    - Digital signal processing
    - Circuits for quantum technology
- *Recent trends*
    - Energy efficiency – the main figure of merit
    - Circuits for milliKelvin operation temperatures
    - Novel cryogenic devices with new functionalities
    - Neuromorphic circuits
- *Conclusions*

Lecturer: Oleg A. Mukhanov and Igor Vernik (HYPRES , USA)

Title: Energy Efficient Superconducting Single Flux Quantum Technology

Abstract: Energy-efficiency has become the dominant metric in choosing technologies for implementing the next generation computing systems. The conventional superconducting Rapid Single Flux Quantum (RSFQ) logic with relatively high static power is replaced with the zero-static power SFQ logics including dc-biased energy-efficient RSFQ (ERSFQ and eSFQ) and ac-biased Reciprocal Quantum Logic (RQL). When combined with a zero-energy ballistic transfer of SFQ pulses over passive transmission lines, the SFQ-type circuits can demonstrate the higher energy-efficiency in complex digital and mixed-signal circuits as compared to any other classical circuit technologies. We will review modern energy-efficient SFQ-type logic families including their design principles, recent circuit implementations focusing on dc-biased ERSFQ and eSFQ logics. We will also describe the overall energy-efficient design approach including input/output room temperature/ cryogenic interfaces. Finally, we will discuss recent innovations which are fundamentally transforming superconducting electronics to achieve new functionalities and enable scalability towards high integration density.

Lecture outline:

- Energy-efficiency – the dominant parameter of modern digital electronics
  - Energy-efficiency bottleneck in electronics
  - Energy in high-end computing
  - CMOS vs Superconducting SFQ circuits
- Addressing energy efficiency in SFQ circuits
  - ERSFQ
  - eSFQ
  - RQL
  - AQFP and nSQUIDs
- Design fundamentals
  - ESFQ design guiding principles
  - eSFQ design guiding principles
  - AC vs DC bias
  - RQL
- Superconducting energy-efficient computing projects
  - US C3 project
  - Japanese computing project
- Energy-efficient Input/Output
  - All-electrical interface
  - Electro-optical interface
- New cryogenic devices
  - Why new devices
  - Superconducting-ferromagnetic devices including superconducting spintronic devices
  - Superconducting nanowire devices

    - New operation regimes
- Fabrication process trends
    - Enabling high-density circuits
- Conclusions

Lecturers: Prof. J. Aarts [University of Leiden, The Netherlands] and Prof. J. Robinson [University of Cambridge, UK]

Title: Superconducting spintronics

Abstract: Superconductors permit the flow of pure charge in the absence of dissipation, but since the Cooper pairs of electrons have antiparallel spins in a singlet state, charge currents cannot carry a net spin. Furthermore, since such singlet pairs are easily disrupted by magnetism, the coupling of superconductivity and ferromagnetism might appear useless for applications in spintronics. However, during the past few years a series of discoveries have shown that, not only can magnetism and superconductivity be made to cooperate, but in carefully engineered superconductor/magnet systems new functionality can be created in which spin, charge and superconducting phase coherence can work together. By combining these different degrees of freedom a whole new spectrum of exciting predictions is waiting to be explored, and the field of superconducting spintronics has emerged.

This six-part lecture course by Dr Jason Robinson and Professor Jan Aarts will review the state-of-the-art in superconducting spintronics with an emphasis on the generation and control of spin-polarized (spin triplet) Cooper pairs. The first lecture will overview the basic properties of magnetic devices including simple concepts in magnetism, spin transport and nanodevice fabrication. The second and third lectures will provide an introduction to the superconductor proximity effect including a detailed discussion on the behaviour of Cooper pairs in magnetically homogeneous (lecture 2) and inhomogeneous materials (lecture 3). The final three lectures will focus on the behavior of triplet pairs in half-metallic ferromagnets (lecture 4), superconducting spin-valves (lectures 5 and 6), and will include a lecture (5) on density of state measurements to probe triplet states in ferromagnetic and superconducting materials.

Lecture 1 (Robinson, 1hr): **Magnetic devices and spintronics**
1.1 An introduction to basic magnetism
1.2 Local and non-local spin transport
1.3 Nanodevice fabrication

Lecture 2 (Aarts, 1hr): Weakly ferromagnetic / superconductor proximity effects with singlet pairs
2.1 Early multilayers
2.2 Pseudo spin valve with singlets
2.3 Josephson junctions with weak ferromagnets

Lecture 3 (Robinson, 1hr): Strongly ferromagnetic / superconductor
proximity effects and triplet pairing
3.1 Josephson Pi-junctions with strong magnets
3.2 Introduction to triplet pairing
3.3 Triplet supercurrents

Lecture 4 (Aarts, 1hr): Half-metallic ferromagnets and oxide devices
4.1 Half-metallic ferromagnetic / superconductor devices
4.2 Oxide devices

Lecture 5 (Robinson, 1hr): Controlling and probing triplet pairs
5.1 Triplet superconducting spin valves
5.2 Spectroscopy studies of triplet states

Lecture 6 (Aarts, 1hr): Half-metallic ferromagnet / transition metal devices
6.1 Half-metallic ferromagnetic superconducting spin-valves
6.2 Lateral Josephson junctions with half-metallic ferromagnets

---

Lecturer: Prof. A. Kimel, [Radboud University of Nijmegen, The Netherlands]

Title: Femtosecond opto-magnetism: from fundamentals to the fastest and least dissipative magnetic recording”

Abstract: Controlling the magnetic state of media with the lowest possible cost of energy and simultaneously at the fastest possible time-scale is a new and great challenge in fundamental magnetism. At the same time this is becoming an increasingly urgent issue in technology, where data centers already consume 5% of the world electricity production. A femtosecond laser pulse excites magnets much faster than characteristic times of atomic, orbital and spin motion and steers magnetization dynamics along yet unexplored, non-thermodynamic routes [1-3]. In my lecture I will discuss these routes [4,5] showing that femtosecond laser pulse facilitates the fastest and least dissipative magnetic recording demonstrated so far [6]. Finally I will discuss the possibilities of employing femtosecond opto-magnetism in magnetic memory compatible with cryo-electronics.

Plan:

1. Light-matter interaction. Magneto-optics and opto-magnetism

2. Ultrafast magnetic phenomena

3. All-optical magnetic recording in metals and insulators

4. Concepts for future devices

Bibliography:

[1] A. V. Kimel, A. Kirilyuk, P.A. Usachev, R.V. Pisarev, A.M. Balbashov and Th. Rasing, *Ultrafast non-thermal control of magnetization by instantaneous photomagnetic pulses*, Nature 435, 655 (2005).
[2] A. Kirilyuk, A. V. Kimel, Th. Rasing, *Ultrafast optical manipulation of magnetic order*, Review of Modern Physics 82 2731-2784 (2010).
[3] C. D. Stanciu, A. Tsukamoto, A. V. Kimel, F. Hansteen, A. Kirilyuk, A. Itoh & Th. Rasing, *All-optical magnetic recording with circularly polarized light*, Phys. Rev. Lett. 99, 047601 (2007).
[4] K. Vahaplar, A. M. Kalashnikova, A.V. Kimel, D. Hinzke, U. Nowak, R. Chantrell, A. Tsukamoto, A. Itoh, A. Kirilyuk, and Th. Rasing, *Ultrafast Path for Optical Magnetization Reversal via a Strongly Nonequilibrium State*, Phys. Rev. Lett. 103, 117201 (2009).
[5] T.A. Ostler et al, *Ultrafast heating as a sufficient stimulus for magnetization reversal in a ferrimagnet*, Nature-Communications 3, 666 (2012).
[6] A. Stupakiewicz, K. Szerenos, D. Afanasiev, A. Kirilyuk, A. V. Kimel, *Ultrafast photo-magnetic recording in transparent medium*, arXiv:1609.05223.

Lecturer: Prof. Y. Tanaka, [University of Nagoya, Japan]

Title: Unconventional superconductivity, quantum topology and odd-frequency pairing

Plan:

(1) Introduction and Andreev reflection

(2) Surface Andreev bound states (SABS) in unconventional superconductors

(3) Topological invariant and SABS (2D)

(4) Topological invariant and SABS (3D)

(5) Topological superconductivity without using unconventional pairing

(6) Topological superconductivity in doped topological insulator & semimetal

(7) Odd-frequency pairing in superconducting junctions

(8) Odd-frequency pairing and Majorana fermion

Lecturer: Dr. H. Boschker, [MPI Stuttgart, Germany]

Title: Interface superconductivity

Abstract: Interface superconductivity offers the possibility to control superconductivity by means of electrostatic gate fields, similar to the control of conductivity in currently used transistors. I will discuss the science of interface superconductivity and the emerging prospects for superconducting electronics.

Plan:

1. History of interface superconductivity
1.1 Early experiments and theoretical proposals
1.2 Cuprates
1.3 $SrTiO_3$
1.4 FeSe

2. The electrostatic field effect
2.1 $LaAlO_3$-$SrTiO_3$
2.2 Electrolyte gating

3. Possibilities for electronics
3.1 Recap field effect transistors
3.2 Superconducting FETs
3.3 Hybrid solutions

4. Artificial atoms from correlated materials

Bibliography

[1] H. Boschker, D. Manske, and J. Mannhart, Physik Journal 15, Nr. 7 (2016) and references therein

Lecturer: Prof. F. Lombardi and Dr. T. Bauch [University of Chalmers, Sweden]

Title: Unconventional superconducting nanostructures for topological quantum computation

Abstract: Topological superconductivity is central to a variety of novel phenomena involving the interplay between topologically ordered phases and broken-symmetry states. An important outcome of this interplay is the possible realization of Majorana bound states on topological surfaces, which are of great interest in fundamental physics and for topological quantum computation. Despite the clear theoretical motivation, the experimental observation of topological superconductivity remains up to now elusive.

The key ingredient is an unconventional order parameter (OP), with an orbital component assuming the form of a chiral px + ipy wave. A clear experimental demonstration of topological superconductivity however has proven to be difficult to achieve. In this contribution we introduce the basics of the Josephson effect implementing topological superconductors. The idea is to give clear insights in the distinct properties of topological junctions when compared with conventional junctions. We will emphasize on the difficulties in experimentally observing the key features of a topological superconductor, i.e. the detection of Majorana bound states.

Plan:

1) Basics of Josephson junction electrodynamics
2) Topological superconductivity (Kitaev model)
3) Topological quantum computation
4) Realization of topological Josephson junctions using proximity effect
5) Detection of Majorana bound states

Bibliography:

1) M. Leijnse, and K. Flensberg, Semicond. Sci. Technol. 27, 124003 (2012)
2) Y. Ando, J. Phys. Soc. Jpn. 82, 102001 (2013)
3) L. Fu, and C. L. Kane, Phys. Rev. Lett. 100, 096407 (2008)

Lecturer: Prof. R. Sobolewski [University of Rochester, USA]

Title: Interfacing Superconductivity with Optics

Lecture plan:

1. **Introduction and Motivation**
2. **Optical Properties of Superconductors**
   (a) interactions of superconductors with lightbasic-physics concepts
   (b) ultrafast photoresponse of superconductors
   (c) photoresponse of superconducting nanostripes
   (d) direct optical modulation of Josephson junctions
   (e) superconductor-ferromagnetic nanostructures

3. **Hybrid semiconductor-superconductor structures**
   (a) metal-semiconductor-metal photodetectors
   (b) GaAs mesoscopic freestanding whiskers
   (c) actively-modulated laser diodes
   (d) magneto-optic and electro-optic modulators
   (e) microwave nanocavity modulators

4. **Examples of opto-superconducting input/output interfaces for digital electronics**
   (a) ultrafast optical-to-electrical input transducers
   (b) ultrafast electrical-to-optical output transducers

5. Conclusion and Future Outlook

Lecturer: Dr. F. Giazotto, [CNR-NANO, Italy] to be announced