Global Research Network "Nanoscience and Engineering in Superconductivity" (NES)

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***Abstract* - We offer a brief overview of the activities of the global research network NES from its concept towards present activities. The mayor goal of this network is to foster and coordinate the scientific activities on nanoscale phenomena in superconducting systems in Europe - in coordination with the network activities in Japan and the USA. The scientific focus ranges from fundamental and experimental aspects, theory and applications, to organization of workshops, conferences and support of education in this field of science.**

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I. INTRODUCTION

The origin of the European Science Foundation (ESF) programme on "Nanoscience and Engineering in Superconductivity" (NES, 2007 - 2012) goes back to the ESF-network "Vortex Matter in Superconductors at Extreme Scales and Conditions" (VORTEX) which was supported by the European Commission until 2003. Strongly motivated by the success and the impact of that ESF programme, the Japan Society for the Promotion of Science (JPSP) launched the "Core-to-core" programme NES. In the USA similar research efforts have been supported via the Argonne National Laboratory and NSF creating a unique coordinated global research network (ESF, JSPS, NSF) in the area of nanoscience in superconductivity.

The main scientific objective is focused on nanoscale phenomena in superconducting systems, *i.e.*, we investigate the effect of the nanoscale confinement of condensate and flux on superconductivity in order to (i) determine the fundamental relations between quantized confined states and the physical properties of these systems, and (ii) to enable "quantum design" of superconducting properties. Along the lines of this main objective, the proposed research is focused on:

- Evolution of superconductivity at nanoscale and superfluidity in restricted geometries,
- Superconductivity in hybrid superconducting – normal (SN) and superconducting – magnet (SM) nanosystems with tuneable boundary condition,

- Confined flux in nanostructured superconductors and hybrid SN and SM nanosystems,
- Josephson effects and tunneling in weakly coupled condensates,
- Fundamentals of fluxonics, superconducting devices.

Results of this research provide a theoretical background for proving the feasibility of the fundamentals of the quantum design and nanoengineering of the superconducting critical parameters. The concept of quantum design is expected to be the tool for developing new elements and systems for microelectronics and information technology (ranging from a magnetometer with improved sensitivity, microwave and THz sensors, detectors for quantum computing and the, so called, Josephson Laser).

II. FACILITIES AND EXPERTISE

The NES program started as a global research network of 85 research institutes (Europe: 68 partners coordinated by V.V. Moshchalkov; Japan: 8 partners coordinated by K. Kadowaki; USA: 9 partners coordinated by W. K. Kwok). This is an open network; additional partners do contribute and participate. In Figure 1, the fifteen supporting EU countries are indicated in green on the map of Europe.

Fig. 1. Map of Europe showing in green the 15 ESF-NES supporting countries: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, Germany, Italy, Netherlands, Norway, Slovakia, Spain, Sweden, Switzerland and United Kingdom. The global research effort also involves NES activities in Japan and the USA.

In addition to the scientific exchange (see below), the integration and coordination of the research facilities of the NES teams towards a European Virtual Institute (EVI) is intended to strengthen the research activities. This includes:

- Integration of the modern sample preparation and nanostructuring (patterning) techniques, ranging from MBE, sputtering, *etc*. to clean room activities (including various patterning technologies), and characterisation methods such as RHEED (reflection high-energy electron diffraction), Auger spectroscopy, RBS (Rutherford backscattering spectroscopy using helium and heavy ions), STM (scanning tunnelling microscopy), *etc*.

- Integration of local probing techniques enabling vortex visualization and condensate wave function mapping with a nanoscale resolution provided by methods such as STM, STS (scanning tunneling spectroscopy), FM (force microscopy), LSM (laser scanning microscopy), scanning Hall probe, magnetic decoration, scanning SQUID microscopy, magneto-optical imaging, and many more. Special emphasis is given to low-temperature probing technologies.
- Integration of bulk integrated response techniques needed for the characterization of on nanostructured superconductors: SQUID-technologies, vibrating sample and torque magnetometry, AC-susceptibility, noise measurements, MOKE (magneto-optic Kerr effect), thermal conductivity, electrical transport measurements (including high frequency responses), ultra low temperature systems, ultrasonic resonance, specific heat, neutron scattering, synchrotron radiation, far-infrared magneto-optics, and nuclear magnetic resonance for nanostructure superconductors.
- Establishing a test platform for the development of new applications, *e.g.*, Josephson junctions technology for the Josephson Laser, ultra sensitive SQUID magnetometers, superconducting qubits, flux -logic, -lenses, -diodes, and –transistors.
- Integration and coordination of the theoretical platform and techniques for the description of the physics of individual nanostructured superconductors. The most important approaches are based on Bardeen-Cooper-Schrieffer theory, (time dependent) Ginzburg-Landau theory, Bogolubov-de-Gennes theory, Richardson's approach to the solution of the BCS Hamiltonian, molecular dynamics simulations, group theory and topology, Monte-Carlo simulations, bosonization, renormalization group calculations, Keldysh formalisms, and Sine-Gordon equation.

Figure 2 presents the methodological structure of the ESF-NES European Virtual Institute. The left-side "tower" represents the categories of scientific (and developmental) activity listed above, from the theoretical, modeling and simulation work on top, through applications, characterization global (integrated response) and local, down to material preparation and sample fabrication. The "windows" on each "floor" represent the specific theories, methods, techniques and approaches also enumerated above.

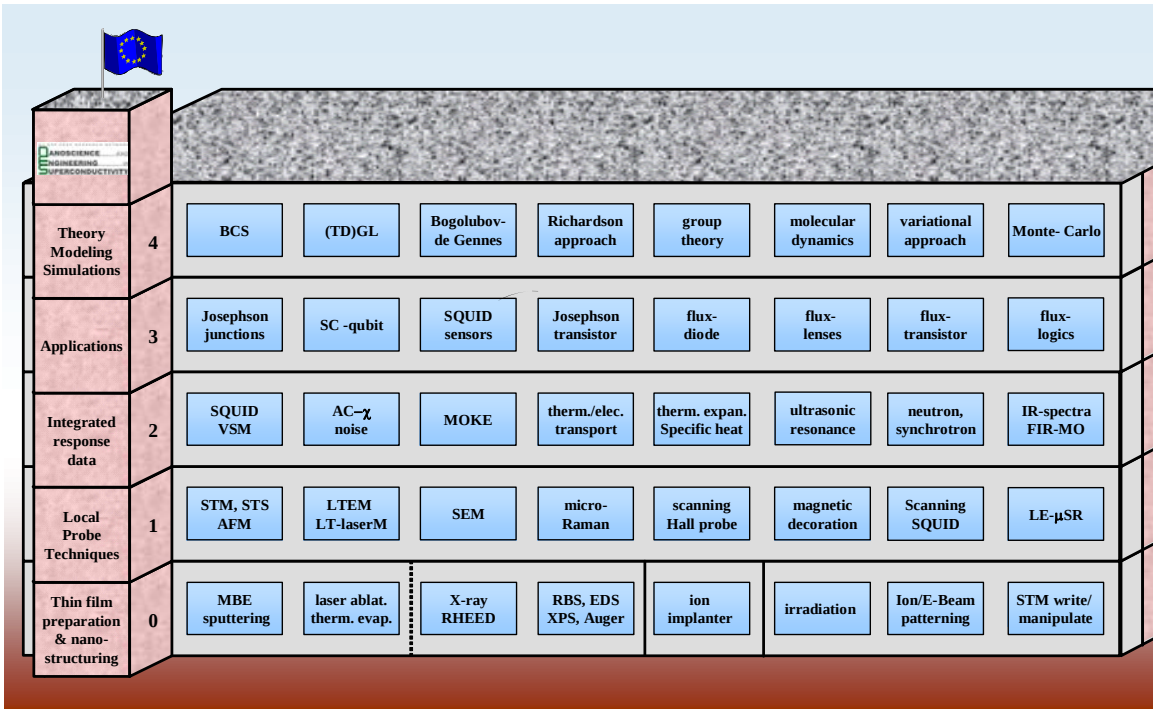

Fig. 2. The methodological structure of the ESF-NES European Virtual Institute.

III.CONFERENCES AND WORKSHOPS

In addition to the coordination of the international research activities and facilities, one of the major goals of the network is the strengthening of scientific exchange, and supporting education for groups active in the field of nanoscience and engineering in superconductivity. The NES program supports short scientific visits and exchange grants (for details, please refer to http://www.kuleuven.be/inpac/nes).

Regular conferences, workshops and schools are periodically organized. Specifically, scheduled are *NES workshops* (at least one focused workshop per year) and *conferences* in the 1st, 3rd and 5th years. The organization of workshops/conferences in a school format offers the opportunity for young researchers and PhD students to learn efficiently about the main trends in the field, and the latest achievements. Several joint ESF-JSPS-USA events are organized with the support from the Japan (JSPS) and USA (NSF) for the participation of scientists from those countries in the NES-ESF events. The following ESF-NES events have been already organized and the first two were held:

8 to 14 September 2007: Joint ESF and JSPS conference on: ***'Vortex Matter in Nanostructured Superconductors'*** (VORTEX V) in Rhodes, Greece. This was the follow-up conference of VORTEX I to Vortex IV; 130 participants attended. The Proceedings of this conference appeared in *Physica* **C 468**, No. 7-10, pp. 499-860 (2008). Proceedings of other past conferences (sponsored by the preceding program) are listed at: http://www.kuleuven.be/inpac/nes/conferences.html

- 4 to 7 June 2008: NES-workshop on ***'Probing superconductivity at the nanoscale'*** in Alicante (Spain). No proceedings are planned.
- 13 to 18 September 2008: NES-workshop on ***'Nanostructured Superconductors: From fundamentals to applications'*** in Freudenstadt-Lauterbad (Black Forest, Germany).
- 17 to 24 September 2009: Joint ESF and JSPS conference in school format on: ***'Vortex Matter in Nanostructured Superconductors'*** (VORTEX VI) in Rhodes, Greece.

Further events are being scheduled and will be announced at the website indicated above. For detailed information and regular updates on the NES activities, please refer to the website: http://www.kuleuven.be/inpac/nes.