Preface

The key technologies of the twenty-first century have been recently identified: energy, transport, nanotechnology, information/communication technology, health care, and environment. Remarkably, for several of them, superconductivity is of special interest, since it deals with the flow of charged particles (electron pairs) without dissipation, thus enabling superior performance needed for new energy-saving technologies. This unique property is a very valuable asset for developing a variety of fascinating technologies belonging to *grand challenges.* To name a few, these technologies range from next generation self-healing superconducting electricity grids, saving up to 15% of the transported electricity, superconducting generators with improved performance deployable among others in off-shore wind turbines or for ship propulsion, superconducting induction heater for power-saving metal processing, International Thermonuclear Reactor (ITER) with the superconducting magnet holding a very hot plasma making possible the fusion reaction, the levitating train operating at speeds exceeding 500 km/h, superconducting elements for quantum computing, to medical diagnostics tomography and magnetoencephalography with highest resolution.

To enable the emerging new technologies, the superconducting materials with a superior performance can be developed by manipulating the appropriate "elementary building blocks" through nanostructuring. For superconductivity, such "elementary blocks" are *Cooper pairs* and *fluxons*.

To support this research, in 2007 the European Science Foundation (ESF) had launched the 5-year Programme *Nanoscience and Engineering in Superconductivity – NES* (http://www.kuleuven.be/inpac/nes/).

Integration and efficient use of the NES experimental and theoretical techniques of the teams from the 15 EU countries participating in this program is achieved through the following activities:

- Implementation of coordinated joint scientific research
- Sharing complimentary equipment
- Joint applications for EU, ESF, and other international projects
- Joint supervision of the PhD work
- Keeping intense electronic exchange of reprints, preprints, data bases, etc
- Joint publication of original and review articles

- Exchange of lecturers, researchers, samples, software, and databases
- Creating and regularly updating dedicated NES website

The main objective of this program is to investigate the effects of the nanoscale confinement of condensate and flux on superconductivity to reveal its nanoscale evolution and to determine the fundamental relations between quantized confined states and the physical properties of these systems. Along the line of the main objective, the ESF-NES research activities are focused on the following topics

- Evolution of superconductivity at the nanoscale

The correlation between the nanograin size and the superconducting gap and the critical temperature T_c is investigated theoretically and experimentally. By systematically reducing the characteristic size of the grains and nanocells the crossover between the bulk superconducting regime and fluctuation-dominated superconductivity regime will be revealed

- Superconductivity in hybrid superconducting – normal (SN) and superconducting – ferromagnet (SF) nanosystems with tuneable boundary condition

Confined condensate is studied in superconducting nano-islands surrounded by normal metallic or ferromagnetic material. The role of proximity effects and the Andreev reflection in modifying the transparency of the sample boundaries will be revealed. The variation of the superfluid density near the boundary is mapped using the local scanning tunneling spectroscopy (STS) techniques. Different vortex configurations, including those with symmetry induced antivortices, and their dynamics are investigated in individual nanostructures of different geometries. Here strong effects of the specific boundary conditions on confined flux and condensate are expected.

- Confined flux in nanostructured superconductors and hybrid SN and SF nanosystems

Nanostructured superconductors and individual nanocells are investigated using local probe techniques, such as scanning tunneling microscopy (STM) and scanning Hall-probe microscopy, the distributions of the order parameter density and local magnetic fields are determined and then compared with the calculations of these parameters based on the solution of the Ginzburg–Landau (GL) equations with the realistic boundary conditions imposed though nanostructuring. Hybrid SN and SF arrays are also studied. Magnetic dots are used to generate local vortex–antivortex loops, which are strongly interacting with the flux lines in superconductors, creating a tunable magnetic periodic confinement. Here we can anticipate a very interesting interplay between flux generated by an applied field and magnetic dipoles, which can substantially enhance flux pinning.

- Josephson effects and tunneling in weakly coupled condensates

Josephson phenomena and phase-shifting effects are investigated in coupled superconducting condensates, where nanoscale coupling can be provided to tune the coupling strength. These phenomena are compared with Josephson effects in superfluids, mostly based on ^{3}He.

- Fundamentals of fluxonics, superconducting devices

Different devices that control the motion of flux quanta in superconductors are designed and studied. One of the focal points is on the removal of trapped magnetic flux that produces noise. The controllable vortex motion is used in nanostructured superconductors for making pumps, diodes and lenses of quantized magnetic flux. Vortex ratchets effects are investigated and then used to achieve vortex manipulation.

This book highlights the recent advances achieved along these research lines in the framework of the ESF-NES Program and presents the new ways superconductivity and vortex matter can be modified through nanostructuring and the use of the nanoscale magnetic templates. The basic nano-effects visualized by the STM/STS techniques, vortex and vortex–antivortex patterns, vortex dynamics, guided vortex motion and vortex ratchets, Josephson phenomena, critical currents, interplay between superconductivity and ferromagnetism at the nanoscale, and potential applications of nanostructured superconductors are presented. The book targets researchers and graduate students working on and/or actively interested in superconductivity and nanosciences.

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