PROJECT PERIODIC REPORT

Grant Agreement number: 214025

Project acronym: MIDAS

Project title: Macroscopic Interference Devices for Atomic and Solid-State Systems: Quantum Control of Supercurrents

Funding Scheme: Seventh Framework Programme, Theme 3: Information and Communication Technologies Collaborative Project: Small or medium-scale focused research project.

Periodic report: 1st ☐ 2nd ☐ 3rd X 4th ☐

Period covered: from 30 to 42 months

Name, title and organisation of the scientific representative of the project's coordinator[1]:

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[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the grant agreement

[2] The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm ; logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.

MIDAS – Macroscopic Interference Devices for Atomic and Solid-State Systems: Quantum Control of Supercurrents

http://www.weizmann.ac.il/chemphys/gershon/midas/

The quantum technologies that are coming to fruition are narrow, isolated niches separated by vast domains of technologies still ruled by classical physics. The formidable challenge of creating a broad quantum-technological base calls for bridging and integrating these niches. In this spirit, we endeavour to capitalize on the remarkable analogies that have recently emerged between two previously unrelated classes of quantum systems with potentially fascinating applications: ultracold-atoms (UCA) degenerated gases and solid-state superconductors (SC). These analogies stem from the notion of macroscopic quantum-coherent transport known as Josephson supercurrent, common to both fields. Building on this, we have studied fundamental and applied aspects of macroscopic quantum coherence/supercurrents in UCA- and SC-based devices through active cooperation between leading teams in the two fields.

This project aims at creating a unified base for genuinely quantum regimes of operation in both fields. This unified base serves a twofold purpose:

i. It allows substantial improvement in the state-of-the-art of both fields: our ability to exploit the properties of macroscopic quantum coherence/supercurrents in novel UCA- and SC-based devices greatly benefits from active cooperation between leading teams in the two fields.
ii. It is used to explore the feasibility of *integrating* the two types of devices. Progress towards this ambitious goal has already been made, with a view towards creating a new quantum technology suitable for various applications .

From both fundamental and applied perspectives, the project has led to several breakthroughs and highly innovative, significant advances: 1) quantum noise understanding and control, which are prerequisites for quantum operations; 2) quantum entanglement of UCA-based Josephson devices (Josephson junctions – JJ) as well as of their SC counterparts; 3) proof of the feasibility of quantum interfaces based on “strong” coupling of SC quantum devices with storage/readout systems based on spin ensembles (NV-centers or impurities in SC, JJ); 4) proof of the feasibility of a hybrid quantum circuit: transfer from the SC device (via a SLR link) to the spin ensemble.

The breakthroughs are the pledged milestones reached in the third period (42-months) which can be detailed as follows:

i. Atomic homodyne technique for detecting continuous-variable entanglement. This breakthrough in UCA ensembles has been developed by Heidelberg jointly with Weizmann.
ii. We implemented SC quantum circuits incorporating coupled / entangled JJ devices usable for quantum information transmission and processing, quantum interferometry and metrology. To this end we have studied the ability to control and manipulate robust (noise resilient) collective variables of entangled elements in UCA JJs (jointly by Heidelberg, Vienna and Weizmann) and in SC JJs (by Grenoble and by Karlsruhe)
iii. We have implemented quantum interconnects / interfaces between NV-center-based quantum memory and readout JJ devices (by Saclay and Vienna, jointly with Weizmann).

This daring undertaking stems from a basic question: can we entangle these two very different types of elements, either by direct coupling, or via electromagnetic field modes? This achieved objective was the most challenging one, aimed at establishing a new quantum technology based on hybrid atomic-solid, macroscopically coherent, modules for quantum information processing (memory + readout).