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 X** **2nd ☐** **3rd ☐** **4th ☐**

Period covered: **from 0** **to 18 months**

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

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Project website[2] address: http://www.weizmann.ac.il/chemphys/gershon/midas/

[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.

Declaration by the scientific representative of the project coordinator1

I, as scientific representative of the coordinator1 of this project and in line with the obligations as stated in Article II.2.3 of the Grant Agreement declare that:

- The attached periodic report represents an accurate description of the work carried out in this project for this reporting period;
- The project (tick as appropriate):

  X has fully achieved its objectives and technical goals for the period;

  ☐ has achieved most of its objectives and technical goals for the period with relatively minor deviations[3];

  ☐ has failed to achieve critical objectives and/or is not at all on schedule[4].

- The public website is up to date, if applicable.
- To my best knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 3.6) and if applicable with the certificate on financial statement.
- All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 5 (Project Management) in accordance with Article II.3.f of the Grant Agreement.

Name of scientific representative of the Coordinator1: .....

Date: ...../ ...../ .....

Signature of scientific representative of the Coordinator1: .....

[3] If either of these boxes is ticked, the report should reflect these and any remedial actions taken.

[4] If either of these boxes is ticked, the report should reflect these and any remedial actions taken.

Publishable summary

This section should be of suitable quality to enable direct publication by the Commission. Please ensure that it is set out and formatted so that it can be printed as a stand-alone paper document not exceeding four pages. This should be readable by a general audience of scientists.

Please include also, as appropriate, diagrams or photographs illustrating and promoting the work of the project, the project logo and relevant contact details.

The address of the project public website should also be indicated, if applicable.

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 have already been made, with a view towards creating a principally new quantum technology suitable for various applications .

From both fundamental and applied perspectives, the project has already led to significant advances: 1) noise understanding and control, which are prerequisites for quantum operations; 2) exploration of the feasibility of interfacing UCA and SC quantum storage/readout systems, in an attempt to bridge these two quantum technologies.
These advances can be detailed as follows:

i. We have explored ways to enhance the sensitivity of SC and UCA devices improving their coherence and operating in the regime wherein quantum noise is dominant. En route to the ultimate goal of approaching the fundamental signal to noise Heisenberg limit. To this end we have reached the two milestones pledged for this (18-month) period:
    1. Environment-induced noise / decoherence has been explored with the view of structurally or dynamically controlling it to reach the quantum limit of performance. Extensive explorations have been jointly undertaken by our Weizmann, Vienna, Charlmers, Naples, Heidelberg, Karlsrushe partners. Topological protection of SC Jjs has been studied by our CNRS partners.
    In addition, fundamental issues of quantum readout have been elucidated by our Saclay partner in SC JJs and by the joint effort of our Vienna, Weizmann and Heidelberg partners in UCA JJs.

2. The inherent (intrinsic) quantum noise of supercurrents has been reduced below their standard (short-noise) limit. This breakthrough of attaining phase-nimber squeezing in UCA JJs has been achieved by our Heidelberg partner.

ii. Significant progress has been made towards our next (30 months) milestones:
   1. We endeavor to implement UCA and SC quantum circuits incorporating coupled / entangled JJ devices usable for quantum information transmission and processing, quantum interferometry and metrology. To this end, we strive to control and manipulate robust (noise resilient) collective variables of at least two entangled elements (or arrays thereof) in UCA JJs and their SC analogues.
   2. We have designed and plan to implement quantum interconnects between UCA- and SC-based quantum memory and readout JJ devices. This daring undertaking stems from a basic question: can we entangle these two very different types of JJ elements, either by direct coupling, or via electromagnetic field modes? This objective is the most challenging, aimed at establishing a new quantum technology based on hybrid atomic-optical-solid, macroscopically coherent, modules for quantum information processing (memory + readout), quantum communication (via interfaces with optical beams) and quantum sensing (ultrasensitive detection and interferometry).

1. Project objectives for the period

Please provide a brief overview of the project objectives for the reporting period in question, as included in Annex I of the Grant Agreement. These objectives are required so that this report is a stand-alone document.

a) Detailed understanding / modeling of environmental (extrinsic) vs. intrinsic fluctuations and noise in SC and UCA JJ devices
b) Study and demonstration of dynamical control of noise decoherence on relaxation in SC and UCA JJ devices

2. Work progress and achievements during the period

Please provide a concise overview of the progress of the work in line with the structure of Annex I of the Grant Agreement.

For each work package *-- except project management, which will be reported in section 3.5-- please provide the following information:*

- *A summary of progress towards objectives and details for each task;*
- *Highlight clearly significant results;*
- *If applicable, explain the reasons for deviations from Annex I and their impact on other tasks as well as on available resources and planning;*

WP1. Fluctuations Exploration and Control in JJ Devices.

(T-theory; E-experiment, Tx,y - Task number, + indicates collaborations, the first partner being the leader)

At this stage of the project we have mostly strived to understand and control the origins and effects of environment-induced noise as compared to intrinsic quantum noise in UCA and SC JJ devices. Our work has identified new possibilities to preserve quantum coherence, by exploring novel methods of dynamical or topological control.

Another principal issue has been the understanding of limitations on the efficiency of Quantum Non-Demolition (QND) readout operations.

WP1 Main Results

(See separate files of Deliverables 1.1, 1.2 and 1.3)

D1.1+D1.2

1. Squeezing of quantum noise (phase-number fluctuations) below the shot-noise limit has been achieved in finite -temperature UCA JJs: a true breakthrough [T1.4/5a]. (E) **[Highlight]**
2. The feasibility of UCA-SC JJ hybridization via a microwave-resonator interface has been explored as a function of the relevant decoherence [T1.4/5d]. This research, pertaining to the core of MIDAS objectives (see WP3) (selected as research highlight by Nature Physics) (T) **[Highlight]**
3. Coherent excitation decay in BEC has been shown to undergo short-time enhancement, which is the fingerprint of the anti-Zeno effect [T1.4/5c]. (E) **[Highlight]**
4. New protocols for the evolution readout of Schrödinger cat states in UCA JJs have been put forward [T1.4/5b]. (T)
5. Analogies between decoherence effects in UCA and SC coherent devices have been elucidated by means of several novel theoretical approaches that go beyond the Markov and Born approximations and apply to multilevel systems coupled to diverse baths: radiative or phonon bosonic baths, two-level fluctuators or spin baths [T1.1a, T1.1b]. (T)
6. The mechanisms of dephasing and decoherence in 1d UCA / BEC have been adequately described for the first time [T1.1c-T1.1e]. (T) **[Highlight]**
7. Quantum nondemolition readout in SC JJs has been explored and the role of decoherence therein has been elucidated. This resolves a key conceptual issue [T1.2b]. (E) **[Highlight]**
8. Low-energy excitations and the ensuing decoherence have been studied in HTS JJ [T1.3a] and in LTS JJ [T1.2a, T1.2e]. (E)
9. Strong-coupling decoherence of SC JJ qubit caused by atomic dipoles (two level fluctuators) has been explored [T1.2c, T1.2d, T1.3*l*]. (E)
10. Significant advances towards the realization of topologically protected SC JJ qubits have been made [T1.3k]. (E)
11. HTS JJ devices have been fabricated and characterized in terms of conductance fluctuations [T1.3b-T1.3i]. (E)

D1.3

1. Novel, efficient schemes of dynamic decoherence control have been devised and implemented in trapped UCA configurations [T1.6a-T1.6g]. (T+E) **[Highlight]**
2. Dynamic control of decoherence and macroscopic tunneling has been explored in SC JJ [T1.7/8b, T1.7/8c]. (T+E)

WP2 progress

(See separate files of Deliverable 2.2)

1. Progress towards studying Andreev states has been achieved [D2.2a, D2.2b]. (E)

2. Studies of entanglement UCA and SC JJ have been performed with encouraging results [D3.1a, D3.1b]. (E)

WP3 progress

(See separate files of Deliverables 3.1, 3.2 and 3.3)

1. UCA-SC JJ hybridization schemes have been studied with encouraging results [D3.3a, D3.3b]. (T)
2. Significant progress has been made towards the experimental implementation of such schemes [D3.3c, D3.3d]. (E)

Validation phase / breakthrough

i. We have demonstrated control of classical and quantum noise and decoherence in UCA devices.

ii. We have elucidated quantum readout limitations in UCA and SC JJs.

3. Deliverables and milestones tables

Deliverables (excluding the periodic and final reports)

Please list all the deliverables due in this reporting period, as indicated in Annex I of the Grant Agreement.
Deliverables that are of a nature other than written "reports", such as "prototypes", "demonstrators" or "others", should also be accompanied by a short report, so that the European Commission has a record of their existence.
If a deliverable has been cancelled or regrouped with another one, please indicate this in the column "Comments".
If a new deliverable is proposed, please indicate this in the column "Comments".

This table is cumulative, that is, it should always show all deliverables from the beginning of the project.

TABLE 1. DELIVERABLES[5]

Del. no.	Deliverable name	WP no.	Lead beneficiary	Nature	Dissemination level	Delivery date from Annex I (proj month)	Delivered Yes/No	Actual Foreca deliver date
D1.1	Theoretical modelling / analysis of non-Markov readout, relaxation and decoherence	1	7	R	PU	18	yes	18
D1.2	Testing designs for readouts, testing role of intrinsic / extrinsic decoherence, probing fluctuations	1	7	R	PU	18	yes	18
D1.3	Testing / demonstration of dynamical fluctuation control	1	7	R	PU	18	yes	18
D1.4	Validation phase / assessment of WP1	1	7	R	PU	18	yes	18
D5.1	Project Website	5	1	O	PU	3	yes	3
D4.8	Preliminary report	4	1	R	PU	9	yes	18
D2.2	Andreev state control	2	4	R		30	progress	
D3.1	Testing, demonstration and analysis of supercurrent entanglement in coupled JJs	3	4	R		30	progress	
D3.2	Fabrication and diagnostics of SC circuits for cryogenic atom	3	2,4	R		30	progress	

[5] For Security Projects the template for the deliverables list in Annex A1 has to be used.

	chips							
D3.3	SQUID and UCA coupled JJ devices	3	4	R		30	progress	

4. Project management

Please use this section to summarise management of the consortium activities during the period. Management tasks are indicated in Articles II.2.3 and Article II.16.5 of the Grant Agreement.

Amongst others, this section should include the following: Changes in the consortium, if any; List of project meetings, dates and venues; Project planning and status; Development of the Project website, if applicable; Use of foreground and dissemination activities during this period (if applicable).

If applicable propose corrective actions.

Changes in the consortium: Our Erlangen team (headed by A. Ustinov) has moved to Karlsruhe after the project start. Annex II and the Periodic Report reflect this change.
List of project meetings: see attached.
Project planning and status: Overall, the project has developed very successfully and has progressed as planned. This has been verified by the Validation Phase for the 18-month period (see attached) which has confirmed that the objectives for the first period have been achieved. Our progress towards the milestones of the second (30-month) period is substantial (see attached) and more diverse than originally foreseen. In particular, new avenues for atomic-SC devices coupling (hybridization) are being explored (see D3.3). One deliverable (D3.2) is in progress and will be delivered later than planned (see D3.2).
Development of the Project website: The website was opened withing 3 months of the project start and is currently used to communicate / pass information among partners, upload publications and presentations at our meetings.
Dissemination activities: Numerous publications and preprints crediting MIDAS, many in high visibility journals, have appeared (see link http://www.weizmann.ac.il/chemphys/gershon/midas/?p=news&id=118). Several joint publications of our partners have been or are being published. MIDAS has been represented by our partners in numerous high profile scientific meetings.

For project presentations in the Midterm Review (Capri, 28-30 Sept. 2009) see link
http://www.weizmann.ac.il/chemphys/gershon/midas/?p=news&id=104
(The presentations are password protected for reasons of confidentiality. You need to login using a username and password provided to you elsewhere).

MIDAS Activities

This report summarizes three meetings organized within the first year of MIDAS.

Vienna symposium, June 2008

Chair: J. Schmiedmayer (Vienna)

This symposium constituted the kickoff meeting for MIDAS and was aimed at establishing a cohesive picture of the research tasks of all partners in the project. The agenda consisted of the following presentations:

1. V. Shumeiko, Chalmers: **Long-time relaxation of SC qubits**
2. T. Bauch, Chalmers: **Macroscopic quantum properties of HTS JJ**
3. G. Kurizki, Weizmann: **Decoherence control for MIDAS**
4. N. Davidson, Weizmann: **Decoherence control of many-body excitations in a BEC**
5. M. Oberthaler, Heidelberg: **Bosonic JJ – Beyond mean-field physics**
6. T. Schumm, Vienna: **Atom chips: quantum manipulation of mesoscopic UCA ensembles**
7. H. Ritsch, Innsbruck / Vienna: **Cavity QED with quantum gases**
8. P. Bertet, CEA Saclay: **How much does continuous measurement of a driven electric circuit affect its quantum coherence?**
9. F. Tafuri, Naples: **HTS JJ and nanostructures in the context of MIDAS**
10. A. Ustinov, Karlsruhe: **Manipulation, decoherence, entanglement of "artificial atom" SC JJ**
11. F. Gerbier, CNRS-Paris: **Quantum spinor condensates**
12. F. Hekking, CNRS-Grenoble: **Josephson Effect in SC Nano-circuits and BEC**

Saclay Symposium, March 2009

Chair: D. Esteve (Saclay)

This meeting was dedicated to WP2 activities within MIDAS. It consisted of the following presentations:

1. P. Bushev, Karlsruhe:
2. W. Guichard, CNRS-Grenoble: **Phase-charge duality in Josephson junction circuites**
3. G. Ferrini and A, Minguzzi, CNRS-Grenoble: **Probing macroscopic superpositions in Bose-Josephson junction**
4. N. Didier, CNRS-Grenoble: **Quantum fluctuations of a Bose-Josephson junction on a quasi-1d ring trap**
5. V. Shumeiko, Chalmers: **Macroscopic dynamics in d-wave JJ**

6. T. Bauch, Chalmers: **Spectroscopy of a LC-shunted JJ**
7. G. Kurizki and I. Mazets, Weizmann+Vienna: **Creation of Schrödinger cat states by measurements**
8. C. Gross, Heidelberg: **Beyond the standard quantum limit in double-well BEC**
9. L. De Sarlo, CNRS-Paris: **Spinor condensates for strongly correlated states**
10. F. Tafuri, Naples: **HTS Josephson nanostructures for quantum devices**
11. T. Schumm, Vienna: **Quantum noise thermometry for coupled 1d Bose gases**
12. D. Vion, Saclay: **Andreev states**

Heidelberg meeting, July 2009

Chairs: M. Oberthaler (Heidelberg) V. Shumeiko (Chalmers) G. Kurizki (Weizmann)

This meeting was dedicated to WP1 activities within MIDAS. It consisted of the following presentations:

1. P. Bushev, Karlsruhe: **Quantum tunneling under rapid modulation of the potential**
2. V. Shumeiko, Chalmers: **Dynamic control of quantum decay**
3. D. D. Bhaktavatsala Rao, Weizmann: **Decoherence and control in spin-Boson systems**
4. N. Bar-Gill, Weizmann: **Decoherence control and entanglement of BEC in a double-well setup**
5. G. Ferrini, CNRS-Grenoble: **Decoherence of mesoscopic superpositions in Bose-Josephson junctions induced by classical noise**
6. T. Bauch, Chalmers: **Spectroscopy of a LC-shunted Josephson junction**
7. D. Vion, Saclay: **Coherence of the transmon qubit and QND high visibility readout**
8. C. Gross, Heidelberg: **Squeezing in Bosonic Junctions**

5. Explanation of the use of the resources

Please provide an explanation of personnel costs, subcontracting and any major direct costs incurred by each beneficiary, such as the purchase of important equipment, travel costs, large consumable items, etc. linking them to work packages.

There is no standard definition of "major direct cost items". Beneficiaries may specify these, according to the relative importance of the item compared to the total budget of the beneficiary, or as regards the individual value of the item.

These can be listed in the following tables (one table by participant):

TABLE 3.2 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 1 (COORDINATOR) FOR THE PERIOD

Work Package	Item description	Amount	Explanations
	Personnel costs	18673	
	Subcontracting		
	Other direct cost	4693	
	Remaining direct costs		
	TOTAL DIRECT COSTS		

TABLE 3.2 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 1 (WEIZMANN) FOR THE PERIOD

Work Package	Item description	Amount	Explanations
	Personnel costs	61127	
	Subcontracting		
	Other direct cost	57264	Consumable, travel, computer
	Remaining direct costs		
	TOTAL DIRECT COSTS		

TABLE 3.2 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 2 (TUW) FOR THE PERIOD

Work Package	Item description	Amount	Explanations
	Personnel costs	47350	
	Subcontracting		
	Other direct cost	14348	
	Remaining direct costs		
	TOTAL DIRECT COSTS		

TABLE 3.2 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 3 (UHEI) FOR THE PERIOD

Work Package	Item description	Amount	Explanations
	Personnel costs	55024	
	Subcontracting		
	Other direct cost	1873	
	Remaining direct costs		
	TOTAL DIRECT COSTS		

TABLE 3.2 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 5 (UNIKARL) FOR THE PERIOD

Work Package	Item description	Amount	Explanations
	Personnel costs	50397	
	Subcontracting		
	Other direct cost	11189	
	Remaining direct costs		
	TOTAL DIRECT COSTS		

TABLE 3.2 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 4 (CEA) FOR THE PERIOD			
Work Package	Item description	Amount	Explanations
	Personnel costs	78424	
	Subcontracting		
	Other direct cost	46726	
	Remaining direct costs		
TOTAL DIRECT COSTS			

TABLE 3.2 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 6 (INST. NAZIONALE) FOR THE PERIOD			
Work Package	Item description	Amount	Explanations
	Personnel costs	72203	
	Subcontracting		
	Other direct cost	10427	
	Remaining direct costs		
TOTAL DIRECT COSTS			

TABLE 3.2 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 7 (CHALMERS) FOR THE PERIOD			
Work Package	Item description	Amount	Explanations
	Personnel costs	63748	
	Subcontracting		
	Other direct cost	14249	
	Remaining direct costs		
TOTAL DIRECT COSTS			

TABLE 3.2 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 8 (CNRS) FOR THE PERIOD			
Work	Item description	Amount	Explanations

Package			
	Personnel costs	135259	
	Subcontracting		
	Other direct cost	70619	
	Remaining direct costs		
TOTAL DIRECT COSTS			

TABLE 3.2 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 9 (TUD) FOR THE PERIOD

Work Package	Item description	Amount	Explanations
	Personnel costs	3932	
	Subcontracting		
	Other direct cost	1101	
	Remaining direct costs		
TOTAL DIRECT COSTS			

(The rest of this template will not be part of the report but be submitted independently via the online application NEF)

Financial statements – Form C and Summary financial report

Remark: This section will not be part of the scientific reporting and should be filled in via the online applicaiont NEF). Simply refer in the scientific report to the online application)

Please submit a separate financial statement from each beneficiary (if Special Clause 10 applies to your Grant Agreement, please include a separate financial statement from each third party as well) together with a summary financial report which consolidates the claimed Community contribution of all the beneficiaries in an aggregate form, based on the information provided in Form C (Annex VI) by each beneficiary.

When applicable, certificates on financial statements shall be submitted by the concerned beneficiaries according to Article II.4.4 of the Grant Agreement.

IMPORTANT:

Form C varies with the funding scheme used. Please make sure that you use the correct form corresponding to your project. Templates for Form C are provided in Annex VI of the Grant Agreement. An example for collaborative projects is enclosed hereafter. A Web-based online tool for completing and submitting the forms C is under preparation. If you have to submit forms C before the tool becomes available, please ask your Commission project officer for an Excel version of the form.

If some beneficiaries in security research have two different rates of funding (part of the funding may reach 75% in reference with Article 33.1 of the EC rules for participation - REGULATION (EC) No 1906/2006) then two separate financial statements should be filled by the concerned beneficiaries and two lines should be entered for these beneficiaries in the summary financial report.

Certificates

Remark: This section will not be part of the scientific reporting.

A copy of each duly signed certificate (depending on whether Expenditure threshold is reached such a certificate will be necessary or not).on the financial statements (Form C) or on the methodology should be included in this section, according to the table above (signed originals to be sent in parallel by post).

Audit certificates that should be send in one package.