WP5 PERIODIC REPORT

Grant Agreement number: 250072

Project acronym: iSENSE

Project title: Integrated Quantum Sensors

Funding Scheme: STREP (ICT-FET-Open)

Date of latest version of Annex I against which the assessment will be made: 4. March 2011

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

Period covered: from 1. July 2012 to 30. June 2013

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.

5. Project management

- ***Management tasks and achievements;***

Management tools

Management of the consortium involves several mechanisms. Each participant is required to provide the respective work package leader with a quarterly status update on the tasks he has carried out. The quarterly status updates are composed into quarterly status update reports for each work package produced by the respective work package leader. They summarize the preceding three months' of research and in particular highlight if the work package is on course to deliver the deliverables and milestones as prescribed in the proposal. If not on course they discuss the reasons and what remedies a sought to improve the situation and what potential knock-on effects there will be on other work packages.

The project coordinator holds meetings with individual work package leaders as required to monitor progress and problems, and apply corrective actions where necessary. They are also utilised by the coordinator to identify points where work packages meet and there are consequent impacts on integration. The level of detail in individual meetings is much higher than achievable in an hour long meeting of the STEM committee. In addition some work packages involving several sites have individual meetings as required to keep the workflow going smoothly. Overall, there have been ~20 such meetings in the reporting period.

Most of the meetings are using electronic communication tools such as Skype, Webex and email extensively. Important documents from meetings are posted regularly on the project wiki.

Following the positive past experience with establishing workgroups to push specific tasks we have further expanded this tool in the management of iSense. The following workgroups have been active during the last project period to push critical tasks:

- Laser Workgroup continuing from the last reporting period to coordinate laser integration activities. This workgroup is close to achieving all its tasks and is going to be phased out in the coming months once all remaining laser systems have been delivered.
- Magnetic Shield workgroup to push the development of a suitable magnetic shield for the iSense apparatus.
- Marketing Task Group to push the film and other outreach activities (see WP4)
- Vacuum workgroup: this workgroup has achieved its goals with the successful implementation of the vacuum system in Birmingham and was phased out.
- Waveguide workgroup to streamline the integrated optics system development.

Research coordination visits between partners

Date	Visiting partner	Visited Partner	Number travelling
28.-29.1.2013	OEAW-IQOQI	LUH	1
30.1.2013	OEAW-IQOQI	UHH	1
3.-9.2.2013	Bham	LUH	2
25.-26.03.2013	SYRTE	Bham	1
29.04.-10.05.2013	SYRTE	LUH	1

In addition we had numerous visits with discussions relevant to iSense between UNott and BHAM within the Midlands Ultracold Atom Research Centre, between UHH, LUH and

FBH within the QUANTUS collaboration as well as between the different subgroups included under CNRS (in particular SYRTE and IOGS).

Co-operation with other projects/programmes

An essential component if the iSense collaboration is to build on the existing expertise and foster synergies between fragmented related programmes across Europe, in particular the FINAQS, LASUS, QUANTUS, SAI, ICE, SOC, QWEP, STE-QUEST, QTEA and Matterwave projects. We co-operate with these projects via the direct involvement of iSense partners. This ensures that iSense technology developments are gauged by the up-to-date needs of the community and will find rapid and sustained use.

The following table gives an overview of particular collaborative activities:

Collaborating project	**Lead Agency**	**Type of Collaboration**	**Collaborative work during reporting period**
QUANTUS	DLR	Knowledge exchange and joint developments	Joint developments on advanced optical telescopes for laser beam shaping. Joint testing of fibre splitter components.
LASUS	DLR	Knowledge exchange and joint developments	Joint laser microintegration strategy developments allowed to develop a new more advanced laser generation to be included in iSense
ICE	CNES	Knowledge exchange and joint developments	Knowledge exchange on magnetic shielding, joint investigation of vacuum strategies
STE-QUEST	ESA	Knowledge exch.	Meetings with mutual representation
QTEA (ITN)	EC	Knowledge exchange and training of students	Meetings with mutual representation and joint training of early stage researchers.
Matterwave	EC	Knowledge exchange	Knowledge exchange on next generation atom chips and guided matterwave interferometers.

In addition iSense is using the respective project meetings to realise informal in-person meetings for the discussion and synchronisation of iSense matters. Some of these are:

Date	Venue	Programme	iSense partners meeting
2.-3.07.2012	Darmstadt	QUANTUS	Bham, LUH, UHH, FBH
27.07.2013	SYRTE	ICAP	SYRTE, OEAW-IQOQI
9.-12.10.2012	Cologne	Q2C5	CNRS, LUH, FBH, UNIFI
24.-26.10.2012	Hamburg	QTEA	Bham, UHH, UNOTT
13.11.2012	Bonn	Quantus	LUH, UHH, FBH
14.-15.02.2013	Hannover	Quantus	LUH, UHH, FBH
18.-22.03.2013	Hannover	DPG Conference	Bham, LUH, UHH, OEAW-IQOQI
8.-12.04. 2013	Birmingham	YAO	Bham, CNRS, LUH, FBH, UHH, UNIFI
19.-25.05.2013	Elba	GWADW	CNRS, UNIFI
23.-24.05.2013	ESTEC	STE-QUEST	Bham, LUH, FBH, UNIFI, SYRTE
7.-8.06.2013	Heraklion	Matterwave	Bham, UNOTT

- ***Problems which have occurred and how they were solved or envisaged solutions;***

We realised during the last review meeting that the original work programme did not foresee sufficient time to plan for magnetic shielding of the probe chamber and for testing and packaging of the integrated optics system. We have implemented a magnetic shielding workgroup and a waveguide workgroup to specifically push these tasks.

The magnetic shield workgroup has since decided upon a baseline shield solution, a strategy for active compensation for initial optimization steps and will finalize the shield design once the first interferometry signals have been achieved.

The waveguide workgroup has made good progress on identifying a suitable company for optical packaging. During the project meeting in Florence it was decided that optical packaging will be outsourced at the appropriate time and that no more action is needed from the waveguide workgroup in this respect. In addition the waveguide workgroup identified and removed a current bottleneck in optical testing of waveguide samples by designing and installing a suitable test system in Nottingham (see Task 1.1). The waveguide workgroup also provided and implemented a detailed wafer processing plan in order to mitigate delays in the realisation of the integrated optical system (see Task 1.1). With these measures we anticipate that the integrated optical system can be realised during the project.

During the project meeting in Florence delays in the microintegrated laser production became apparent, which have increased since. These delays are caused by technical risks such as thermal problems and failing thermosensors. The Laser Workgroup has been very helpful to minimize the consequences of these risks, however there is still a significant delay in the delivery of the integrated laser systems. We have thus in addition implemented an intermediate solution based on commercial laser systems, which allow establishing and optimizing system operation until the laser systems become available. This minimizes the overall project delay and we anticipate to be able to achieve full sensor operation before the end of the project.

There is a delay in the delivery of the chip current driver and the DDS boards. We will use standard power supplies and have identified suitable commercial DDS systems to allow optimization of the system until the respective boards are delivered. The impact on the overall objectives of the project will be thus minimized.

- ***Changes in the consortium, if any;***
  Florian Schreck the key representative from OEAW-IQOQI has accepted an offer from University of Amsterdam and will move autumn 2013. The respective changes will be discussed during the review meeting.

- ***List of project meetings, dates and venues;***

Date	Venue	Purpose	N attending
12.-14.9.2012	Brussels	iSense progress, management and review meeting	25
30.01.2013	Teleconference	iSense progress meeting	9
11.-12.04.2013	Florence	Project progress and management meeting	18
28.05.2013	Teleconference	Laser mounting strategies	4
18.06.2013	Teleconference	iSense film planning	5

- ***Project planning and status;***

The project is meeting its scientific goals and despite some delay is anticipated to hit all the Milestones. The next year will see a strong focus on finalising and optimizing the iSense gravity sensor as well as a demonstration of the integrated optics system as important ingredient to the iSense technology platform. The respective work will mainly be done at Bham and UNOTT, both of which have significant remaining resources to address the associated work. This work will be supported and extended by the entire consortium in terms of expertise in subsystems and developments reaching into the future beyond iSense.
Just before the review meeting we will discuss how to take the results of iSense forth in research and initiate workgroups to form consortia to prepare respective proposals. The ICT2013 meeting in Vilnius will provide a platform to demonstrate iSense to an interdisciplinary scientific community and make further contacts for these consortia. In Spring 2014 a project meeting at TOPTICA is planned with a focus on commercial outlook and dissemination.

The Gant chart below has been modified from the original plan (green) to provide an overview of the project status and the anticipated further work needed taking into account the incurred delays. Plain red indicates additional work on the full range of subtasks, patterned red indicates additional work needed on a small set of subtasks or small delays in the overall, but running work. Patterned green indicates reduced work. The task specific details will be discussed below the Gant chart.

Month	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**	**30**	**33**	**36**	**39**	**42**	**45**	**48**
WP1: Integrated Laser System																
T1.1: Integrated optics modules																
T1.2: Micro-integrated diode laser																
T1.3: Integration of the entire optical system for the iSense sensor																
T1.4: Fibre splitter module																
T1.5: Visible diode laser systems																
WP2: Science Chamber and Scheme																
T2.1: Interferometer Scheme.																
T2.2: Low power atom chip																
T2.3: Vacuum chamber																
T2.4: Alt. atoms and schemes																
WP3: Integrated Sensor																
T3.1: Electronics																
T3.2: Integrated gravity sensor																
WP4: Dissemination																
T4.1: Communication tools																
T4.2: iSense film																
T4.3: Outreach campaigns																
T4.4: Portfolio and concertation activities at FET-Open level																
T4.5: Marketing																
T4.6: Sensor deployment																
T4.7: Foreground																
WP5: Management																
T5.1: Consortium start-up																
T5.2: Interface Workshop																
T5.3: Yearly Review meetings																
T5.4: Project management																
T5.5: Communication managemnt																
T5.6: Awareness and Societal Implications																
T5.7: Final Report																

Task-specific project status and planning

Task 1.1: **>12 months** more work needed
This task is significantly delayed, which is mostly due to the late start caused by the originally responsible partner QinetiQ leaving the consortium, but also due to some unforeseen problems in the optimization and characterization of integrated waveguides. As discussed in the WP1 section we have run significant optimization processes in wafer manufacture and installed a dedicated optical characterization system in Nottingham. In addition in response to an evaluation of the efforts in mask manufacture it was decided to parallelize the initially sequential optimisation process. We now have produced wafers with all iSense subsystems and are working on the characterization. If we receive sufficiently positive results from the characterisation and only have to allow for one iteration of wafer manufacture it should be possible to finalise the integrated optical system within the duration of the project. However there is a significant risk that more optimisation will be needed, which could be reduced by a project extension.

Task 1.2: **~9 months** more work needed
The final delivery of all diode laser modules was in total delayed by 9 months, but they have now all been delivered to Birmingham. The time delay was partially compensated by temporally using commercial laser systems as replacement, however there was a knock-on effect on the iSense film (task 4.2), the work on which was shifted in order to include the laser systems in the iSense sensor. In addition the sensor integration (task 3.2) was slightly delayed due to the extra work in implementing the temporary commercial laser solution.
The microintegrated spectroscopy setup is the only part in this task, which is still outstanding, with a delivery planned in May 2014. We have mitigated the effect of this delay by implementing a temporary alternative spectroscopy solution. Part of the delay is caused by the decision to implement a more advanced technology solution for this part, than originally planned, in order to improve stability and size. Some small amount of extra work will be required until close to the end of the project to finalize this part and implement it into the sensor. Again a risk of late delivery might be mitigated by an extension of the project.

Task 1.3: **1 week to 3 months** more work needed
This task can be completed with the fibre optical light delivery system within a week of extra work, when the spectroscopy module from task 1.2 arrives. If the integrated waveguide subsystems form task 1.1 become available, there will be 3 months work needed to integrate them into the system and reoptimize the sensor.

Task 1.4: completed
This task was delayed by 3 months due to late delivery of the fibre splitter device, which is now integrated into the sensor and working well.

Task 1.5: ongoing
As planned.

Task 2.1: This task was completed early.

Task 2.2: Completed
The final delivery of the chip was delayed by 6 months due to unforeseen vacuum problems caused by commercial parts. These are now solved and the chip is operating in the sensor.
It was decided to reduce work on the subtask of transparent atom chip materials, as there have been respective reports from the international community, which show in-principle feasibility. This frees

up some resources in Nottingham for the optical characterisation of integrated waveguides in task 1.1

Task 2.3: completed early

Task 2.4: ongoing
As planned

Task 3.1: partial extra work needed until month 45
All electronics modules have been designed and most of them have been delivered to Birmingham to be integrated into the sensor. The only missing parts are the Chip current drivers (expected October 2013) and the DDS boards (expected March 2014). The delay in the DDS boards is due to unforeseen complexity in the programming of their firmware. We have identified commercial solutions for a temporary replacement and will implement these, in order to minimize impact on the overall programme.

Task 3.2: ongoing, but ~ **3 months delay**
There are some delays in the integration of the iSense sensor due to the delays in other WPs. We have been able to mostly compensate for the effects of these delays using alternative solutions, but some extra work was needed in order to implement these. Overall we are confident to be able to present a working interferometer at the last review meeting, however there is a significant risk, that the sensitivity will be lower than hoped for. This might be reduced by a project extension allowing for more optimization time.

Task 4.1, 4.3, 4.4, 4.5, 4.7: ongoing as planned

Task 4.2: shifted by 5 months to allow maximum impact of the film

Task 4.6: at risk to be delayed
The sensor deployment will depend on the optimization, which was delayed as discussed under task 3.2. An extension of the project would mitigate this risk.

WP5: ongoing as planned in all tasks.

- ***Impact of possible deviations from the planned milestones and deliverables, if any;***
  We anticipate the delays in achieving the iSense milestones and deliverables to cause only minor impact on the overall project vision.

- ***Any changes to the legal status of any of the beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs;***
  We can confirm that there have been no legal changes to the status of any of the beneficiaries.

- ***Development of the Project website, if applicable;***
  The project has two web interfaces: an internal wiki and a globally accessible website. The wiki is being used extensively to support management activities. Project meeting minutes, documents on integration, slides from presentations and many other documents are stored on the wiki. The global website summarizes the project, introduces its members and disseminates new results. It is planned to expand this website during the next year.

- ***Use of foreground and dissemination activities during this period (if applicable).***

Publications

1. S. Pelisson, R. Messina, M.-C. Angonin, and P.31 Wolf, Dynamical aspects of atom interferometry in an optical lattice in proximity to a surface, Phys. Rev. A **86**, 013614 (2012).
2. T. Bourdel, “Phase diagrams of two-dimensional and three-dimensional disordered Bose gases in the local density approximation”, Phys. Rev. A **86**, 063626 (2012).
3. S. Stellmer, B. Pasquiou, R. Grimm, and F. Schreck, Creation of ultracold Sr2 molecules in the electronic ground state: Phys. Rev. Lett. 109, 115302 (2012), arXiv:1205.4505.
4. F. Sorrentino, A. Bertoldi, Q. Bodart, L. Cacciapuoti, M. de Angelis, Y.-H. Lien, M. Prevedelli, G. Rosi, and G. M. Tino, Simultaneous measurement of gravity acceleration and gravity gradient with an atom interferometer, Appl. Phys. Lett. **101**, 114106 (2012)
5. M. G. Tarallo, A. Alberti, N. Poli, M. L. Chiofalo, F.-Y. Wang, and G. M. Tino, Delocalization-enhanced Bloch oscillations and driven resonant tunneling in optical lattices for precision force measurements, Phys. Rev. A **86**, 033615 (2012).
6. B. Olmos, D. Yu, Y. Singh, F. Schreck, K. Bongs, and I. Lesanovsky, Long-Range Interacting Many-Body Systems with Alkaline-Earth-Metal Atoms: Phys. Rev. Lett. 110, 143602 (2013), arXiv:1211.4537.
7. M. G. Tarallo, N. Poli, F.-W. Wang and G. M. Tino, Coherent control of quantum transport: Modulation-enhanced phase detection and band spectroscopy, Eur. Phys. J. **217**, 207 (2013)
8. S. Stellmer, R. Grimm, and F. Schreck, Production of quantum-degenerate strontium gases: Phys. Rev. A 87, 013611 (2013), arXiv:1212.2539
9. S. Stellmer, B. Pasquiou, R. Grimm, and F. Schreck, Laser cooling to quantum degeneracy: Phys. Rev. Lett. 110, 263003 (2013), arXiv:1301.4776. In the media: physicsworld
10. T. Vanderbruggen, R. Kohlhaas, A. Bertoldi, S. Bernon, A. Aspect, A. Landragin, and P. Bouyer, “Feedback Control of Trapped Coherent Atomic Ensembles”, Phys. Rev. Lett. **110**, 210503 (2013).
11. B. Pelle, A. Hilico, G. Tackmann, Q. Beaufils, F. Pereira Dos Santos, "State-labelling Wannier-Stark atomic interferometers", Phys. Rev. A 87, 023601 (2013).

Conference/Workshop talks

1. F. Schreck, Strontium quantum gases: Fermions with SU(N) spin symmetries and more, Quark Gluon Plasma meets Cold Atoms - Episode III, 25-31 August 2012, Hirschegg, Austria.
2. Sorrentino, Gravity measurements with atom interferometry, Q2C5 conference, Cologne, 9-12 October 2012.
3. S. Stellmer/ B. Pasquiou, New tricks and old ideas: News from the Innsbruck Strontium Experiment, 5th Group-II-meeting, Tokyo, Japan, 11.October 2012.
4. F. Schreck, An outlook on ultracold strontium: laser cooling to quantum degeneracy, molecules, and many-body physics, Cold Atom Outlook 2012 - A European Endeavour, Aarhus, Danmark, 2. November 2012.
5. Protecting ensemble atomic coherence with weak measurements and feedback, Graduate College course in cold atoms and metrology, University of Hannover, Germany, 13 December 2012.
6. S. Stellmer, Laser cooling to quantum degeneracy, SFB meeting, Vienna, 13 December 2012.
7. Cold atoms, weak measurements and feedback for timekeeping, Lectio Magistralis at the opening of the Academic year, PhD School, University of Trento, Italy, 27 February 2013.

8. F. Schreck, A new dog for new tricks: Strontium for laser cooling to BEC, molecules, and many-body physics, FINESS 2013, 20 February 2013.
9. K. Bongs, “Mapping the Underground”, Global Engagements Workshop, Nottingham, 6 March 2013.
10. S. Stellmer, Laser cooling to quantum degeneracy, Workshop Continuous Sources of Quantum Matter, Freudenstadt (Deutschland), 13 March 2013.
11. F. Schreck, Towards RbSr ground-state molecules: Rb / Sr double BEC & STIRAP to Sr2 molecules, KITP Conference: New Science with Ultracold Molecules, 15 March 2013.
12. A. Bayerle, Double Bose-Einstein condensate of rubidium and strontium, DPG Frühjahrstagung, Hannover, 20 March 2013.
13. S. Stellmer, Laser cooling to quantum degeneracy, DPG Frühjahrstagung, Hannover, 22 March 2013.
14. F. Schreck, Repulsive polarons in a strongly interacting Fermi mixture, Newspin 3, Mainz, 3 April 2013.
15. T. Mazzoni, Gravity measurements with ultracold strontium atoms in an optical lattice, YAO 2013, Birmingham, 8-12 April 2013.
16. F. Sorrentino, The MAGIA experiment: current status and future prospects, GWADN 2013, Elba, 19-25. May 2013
17. B. Pasquiou, Double BEC of Rb and Sr: the power of sympathetic narrow-line cooling, DAMOP 2013, 6 June 2013.
18. F. Schreck, Laser cooling to quantum degeneracy, DAMOP 2013, 7 June 2013.
19. K. Bongs, “Quantum Sensors for Gravity and Time”, JCQ Launch Workshop, Newcastle, 26 June 2013.

Conference/Workshop posters

1. F. Pereira dos Santos, B. Pelle, A. Hilico, Q. Beaufils, G. Tackmann, S. Pélisson, R. Messina, M.-C. Angonin, P. Wolf, "A trapped atom interferometer for short range forces measurements", ICAP 2012, The 23rd International Conference on Atomic Physics, Palaiseau (France), 23-27 July 2012.
2. S. Stellmer, Laser cooling to quantum degeneracy, 5th Group-II-meeting, Tokyo, Japan, 11 October 2012.
3. B. Pasquiou, Production of ultracold Sr2 molecules in the electronic ground state, 5th Group-II-meeting, Tokyo, Japan, 11 October 2012.
4. K. Bongs, Miniaturization of Technology for Atom Interferometric Sensors, ITF Energy Oil and Gas Event, Aberdeen, 1. November 2012.
5. J. Malcolm, “iSense”, IOP Quantum Technologies Meeting, IOP, London, 17 December 2012.
6. J. Malcolm, “iSense”, DSTL Town Meeting: Precision Timing (and Navigation) technology, ISIC Harwell, 7 March 2013.
7. S. Tazanova, Towards the creation of ground-state RbSr molecules, DPG Frühjahrstagung, Hannover, 21 March 2013.
8. J. Malcolm, “iSense”, Young Atoms Opticians conference 2013, Birmingham, 10 April 2013.
9. A. Hilico, B. Pelle, M.-K. Zhou, Q. Beaufils, G. Tackmann, S. Pélisson, M.-C. Angonin, P. Wolf and F. Pereira Dos Santos, "A trapped atom interferometer for the measurement of short range forces", ICOLS, 9-14 June 2013, Berkeley (USA)
10. B. Pelle, A. Hilico, M.-K. Zhou, Q. Beaufils, G. Tackmann, and F. Pereira dos Santos, "A trapped atom interferometer for the measurement of short range forces", ECAMP11, 24-18 June 2013, Aarhus (Denmark)