PROJECT PERIODIC REPORT

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Project acronym: ISENSE

Project title: Integrated Quantum Sensors

Funding Scheme: STREP (ICT-FET-Open)

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

Period covered: from 1. July 2010 to 30. June 2011

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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.

Declaration by the scientific representative of the project coordinator[1]

I, as scientific representative of the coordinator[1] 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.
- 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 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 Coordinator[1]: ....Kai Bongs...........

Date: 30/09/2011

Signature of scientific representative of the Coordinator[1]: ....

[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.

1. Publishable summary

iSense – INTEGRATED QUANTUM SENSORS

Project objectives

The iSense project aims to bring the latest developments in ultracold atom science to practical applications by developing the technology that will turn laboratory-based instrumentation into portable and robust instruments and sensors.

State-of-the-art ultracold atom experiments, which cool down a cloud of atoms to temperatures close to the absolute zero with the aid of lasers, have demonstrated an exquisite degree of control over matter. At record-low temperatures, close to the absolute zero, it is now possible to harness the quantum nature of matter in order to develop futuristic applications involving delicate sensing or secure communications.

In this context, the goal of iSense is two-fold. First, it develops a set of tools and technologies that can be used as basic blocks to build a robust and portable device based on ultracold atoms. Second it aims to demonstrate this new technology platform by realising an ultracold-atom-based instrument able to measure the gravitational field with a precision comparable to the best commercial instrument, but in a more compact and portable format.

In the future, we hope that iSense will open the door to the integration of ultracold atom technology to fields as diverse as geodesy, mineral prospection, satellite communications, portable atomic clocks, secure quantum communications, and fundamental research.

A typical ultracold atom experiment is complex enough to fill a room. It is composed of a vacuum chamber that contains the gas of ultracold atoms, a number of lasers with their stabilisation optics and electronics, electromagnets to create magnetic fields and an optical table to hold all this equipment. It also consumes a lot of energy, more than a powerful electric heater.

The challenge of iSense is to reduce the size and the energy consumption of the apparatus to make it fit in a volume that could be manipulated and carried around by a single person, something like the size and weight of a large backpack. It should also be autonomous.

Work performed since the beginning of the project

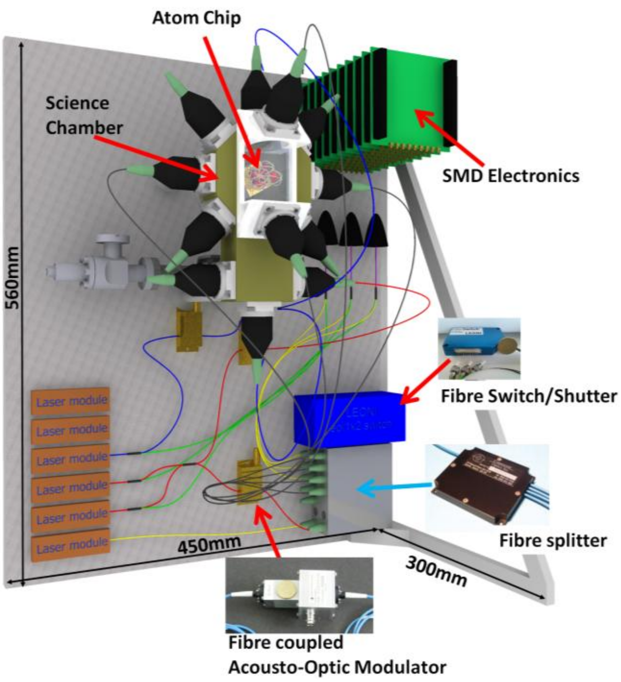
During the first period of the project, we have initiated the design and/or tested the concept of all the components of the technology platform required to build the iSense gravimeter. This includes an integrated optical system, micro-integrated laser modules, electronics modules, an atom chip and a vacuum chamber. The general interfaces between all the components have been determined, leaving room for optimisation at the module level.

The project website, internal project Wiki and communication tools have been established.

Main results achieved so far

Micro-integrated laser systems

Laser cooling of atoms requires high-quality lasers with significant power. We are improving the technology of semiconductor lasers (laser diodes) to make them suitable for ultracold atom sensors.



The micro-integrated laser production is well in schedule. DFB-RW lasers have been produced with the required parameters. The power amplifier wafers have been processed and we are awaiting first measurements. The development and design of extended cavity diode lasers, which have a narrow linewidth, has been completed and components sent out to manufacture. First prototypes are expected in late August 2011. Miniaturized spectroscopy cells, which allow the lasers to stay tuned to the atomic resonances, have been produced and tested. Fibre coupling methods and Zerodur baseplate technologies have been tested on track for integration of the entire laser system.

Integrated optical splitter device

The iSense project seeks to drastically reduce the footprint of the optical system by combining the optical elements on a single semiconductor chip. It will integrate the guiding, splitting, combining and switching of the laser beams.

Nottingham has taken over the tasks assigned to QinetiQ in the original Annex-I and has successfully started modelling work for integrated devices. First samples shall be produced in autumn 2011. The work on an alternative free-space optical delivery module has started ahead of schedule with a preliminary system design and some component tests.

Electronics

The optical set up is composed of many active components, such as the lasers, switches, frequency modulators, that require their own electronic drivers and need to be run synchronously.

The ongoing development of small electronics modules is on track. Several modules such as high-current power amplifier drivers, temperature controllers, a switching module and a housekeeping module have been finalised.

Atom Chip

The trapping of ultracold atoms requires a magnetic field in addition to the lasers. A modern approach consists in generating the magnetic field with copper tracks running on a small substrate, a so-called atom chip.

A first generation stand-alone atom chip has been demonstrated to trap atoms in a magneto-optical trap with a power consumption below 5W, although a current requirement of 100 A. A second generation chip has been designed with a current requirement of 20 A and will be fabricated within the next months.

Science Chamber

Ultracold atoms needs to be perfectly insulated from the rest of the world and are therefore placed in a vacuum chamber. The chamber is an assembly of glass parts, to let the laser light in, and metal part, to hold pumps and various electrical connexions.

Various glass-metal bonding techniques have been tested. Non-glue techniques have proven susceptible to failure, such that the decision was taken to base the iSense vacuum chamber on modern gluing technology.

Interrogation Schemes

Quantum sensing with ultracold atoms is based on atom interferometry, where matter waves replace the light waves found in conventional interferometers. We develop new interferometry schemes aiming at reducing the amount of space required and therefore reducing the final size of the sensor.

Wannier-Stark, Modulation and Levitation interferometry schemes have been implemented and tested. The optimization of the sensitivity and accuracy of these schemes is under way, although a preliminary analysis indicates that the Levitation scheme is unlikely to reach the iSense sensitivity target.

Dissemination and collaboration

The iSense consortium has installed a website, published 4 papers and contributed to 14 conferences. In particular the iSense project was also represented at the FET11 conference.

Expected final results

At the end of the project, we expect to have developed a general technology platform proven by the demonstration of a self-contained backpack-size, “turn-key” quantum system. In particular we expect the following final results:

- iSense will create a set of integrated optics integrating beamsplitting and amplitude modulation functions for cold atom applications at 780nm using GaAs technology.
- iSense will create a step-change in laser technology based on the novel optical microbench technology used by the partner FBH with a factor of 100-1000 volume size reduction as compared to the current state-of-the-art. iSense will deliver narrow linewidth MOPA-lasers and ECDLs in microbench technology also going to more complex systems, like ECDLs with an atomic reference cell integrated on the micro-bench.
- iSense will realize novel low-power atom chips, which can operate without external coils and will investigate optimization for sensor operation and transparent conductor technology.
- iSense will realize novel compact and fully UHV compatible systems with full anti-reflection coating as necessary for ultra-precise sensor applications. The size of below 0.001 m^3 will be more than 1order of magnitude smaller than the current state-of-the-art
- iSense will develop a SMD-based electronics platform with coherent computer control, such that fully autonomous operation of cold atom experiments will be possible for the first time. As

a particular point, iSense will develop a compact precision radiofrequency reference source for application in atom sensors.
- iSense will develop and optimize “trapped” schemes for highest precision measurements – removing the need for free-fall distances and allowing for compact local shielding of magnetic fields and other external disturbances. In particular schemes based on Wannier Stark states, Bloch oscillations or levitation by repeated Bragg diffraction will be studied.
- Isense will realize a force sensor with 10^{-9}g sensitivity potential in a volume <$0.1 m^3$

Potential impact and use

The field of cold atom research is currently facing a paradigm change, in which interest shifts from the quantum gas as such to its exploitation in precision sensors, quantum simulation and quantum ICT. With research and innovation now focusing on these applications, there is an emerging need for a small, robust and reliable technology platform delivering cold atoms as a readily available quantum resource.

The iSense project will provide an enabling platform for the development and exploitation of commercial cold atom quantum sensor applications. In addition to being of potential benefit to the entire cold atom research community, this platform will also deliver the underpinning technology for a novel approach to quantum ICT research. In particular, the iSense integrated gravity sensor technology, which will allow us to “see” what the underground is made of, has the potential to revolutionize geophysical exploration and geophysics research. It would provide superior sensitivity for mapping of e.g. oil fields, mineral deposits or monitoring of carbon capture sites, helping to secure future energy supply as well as controlling CO2 emissions. On satellite missions as currently discussed by ESA (e.g. APPIA project) cold atom gravity sensors could provide a new quality of global geodetic data allowing e.g. to monitor water circulation at an unprecedented level and thus providing crucial tests to current climate models. In addition iSense lays the foundations for broadening of its technology platform to small scale optical frequency standards, which could provide ultra-precise timing in future high-capacity communication networks.

Scientifically, the iSense project will provide new insights into the major factors influencing “local” cold atom inertial sensing schemes, including sensitivity scaling, fundamental decoherence effects and technical noise limitations. Using these schemes the iSense project aims at precision measurements of h/m for Rubidium atoms, the measurement of the Casimir force and the search for novel forces leading to deviations from the 1/r2 gravitational potential. Furthermore, iSense will investigate the 83Sr isotope as well as various Yb isotopes with respect to collisional parameters and the possibility to create a quantum degenerate sample as a potential resource for frequency sensor applications. In addition iSense will advance the state of knowledge and ensure a leading position of EC research in mobile quantum sensing activities.

Contact and further details: http://www.isense-gravimeter.com/

2. Project objectives for the period

The below overview lists all the task-related objectives, which were due to be started/completed during the reporting period.

WP1 – Integrated laser system:

Task 1.1 – Transfer telecom technology integrated optics to 780nm operation (months 7-16).

Fabrication of passive test structures to determine dependencies of loss processes, mode control and polarisation properties of optical GaAs waveguide structures working at 780nm. In particular dependencies on material parameters and geometry shall be tested, including layer thickness, Al concentration and waveguide shape.

Task 1.2 – Micro-integrated extended cavity diode lasers for Rb spectroscopy (months 1-20).

The laser diode chip, the optical grating, collimation micro-optics, and miniature optical isolators will be integrated on a microbench with a volume of 5 x 2.5 x 1 cm^3. The lasers will provide 50 mW output power with a short-term (10 µs) linewidth of 100 kHz. The lasers will be tuneable by +/- 50 GHz.

Task 1.3 – Evaluation of waveguide to fibre coupling methods (months 1-16).

The aim will be to achieve a coupling efficiency above 70% from waveguide to fibre with linear polarisation to be maintained to better than 1:100.

WP2 – Science chamber and scheme:

Task 2.1 – Realization of gravity measurements with three different schemes (months 1-18)

We are aiming at a sensitivity better than 10 µgal/$Hz^{1/2}$ while keeping the atoms in a probe volume below 1 cm^3 with the following schemes:

- Wannier Stark interferometer. The interferometer will be realized with atoms trapped in a far detuned optical lattice, and manipulated thanks to two-photon Raman transitions. The beam splitting process will be optimized for large wavepacket separations and increased interferometer sensitivity.
- Realization of Bloch oscillations in optical lattices. Sources of decoherence will be investigated. Comparison with Bloch oscillations with Sr atoms
- Realization of the Atomic Leviation scheme. This scheme will impart to free falling atoms repeated momentum transfers with two photon transitions, allowing them to levitate. Comparison of "classical" and "quantum" levitation schemes.

Task 2.2 – Layout of low power chip design and support structure (months 1-12)

Layout of a chip design with power consumption below 1W and no external coil requirement. This design will focus on providing a number of microwire based magnetic traps, optimized for fast and efficient loading and cooling of more than 10^7 Rb atoms and transfer of more than 10^4 atoms to optical lattices used in the sensor. Design of a chip support structure fitting in a volume of 100 cm^3 and weighing below 500g when fitted with the chip. This structure will encompass a replaceable header structure that will be directly attached to the atom chip, an integrated larger (millimetre sized) copper trapping structure and broad current sheets for generating homogeneous fields for both chip based and support structure based magnetic traps.

Task 2.3 – Investigation of glass-glass and glass-metal bonding for vacuum chamber (months 1-12)

The main purpose of this task is to investigate glass/metal and glass/titanium bonding with the aim to achieve window seals with a leak rate below 10^{-12} mbar l/s.

– Investigation of the mechanical interface between vacuum chamber and optical/magnetic components (months 1-24)

Aim is a total volume of the science chamber including all interfaces below 10l with a weight below 5kg.

Task 2.4 – Demonstration of alkali-earth apparatus (months 1-12)

This task will be focused on the demonstration of experimental apparatus for cooling and trapping of more than 10^5 Sr and Yb atoms based on current technology developed for compact and transportable setups.

WP3 – Integrated Sensor

Task 3.1 – Determination of types of modules and their specification and quantities (months 1-4)

– Develop basic electronic modules which are computer controlled (months 1-18)

This involves modules like Diode-laser current source, temperature controllers, RF frequency generators, demodulation for frequency offset locking, demodulation for spectroscopy locking.

– Develop FPGA based laser frequency control methods (months 1-24)

– Develop a compact frequency reference chain operating at 6.8 GHz (months 1-27)

Task 3.2 – Sensor design workshop (month 4)

– Design specifications for vacuum chamber and chip design (month 1-24)

WP4 – Dissemination

Task 4.1 – Public web page (months 1-48)

– Internal web page (months 1-48)

– Communications tools (logo, business cards, power point template) (months 1-3)

Task 4.3 – Outreach campaigns (months 1-48)

Task 4.4 – Contribution to portfolio and concertation activities at FET-Open level (months 1-48)

Task 4.7 – Use and dissemination of foreground (months 1-48)

WP5 – Management

Task 5.1 – Consortium Start-up (months 1-3)

Task 5.2 – Interface workshop (month 4)

Task 5.3 – Yearly review meetings

Task 5.4 – Project management (months 1-48)

Task 5.5 – Communication management (months 1-48)

3. Work progress and achievements during the period

WP 1- *Integrated Laser System*
Work package leader: UHH

Introduction
In work package 1 we aim for the realization of a highly miniaturized but nevertheless flexible laser system for cooling neutral atoms. The laser system can be described by three main components. That is the laser itself, the splitting module and the connection to the rest of the world, i.e. the coupling of the light into optical fibres which will work as connection between laser system and vacuum system.

To achieve the realization of all this, the work package has been divided into five tasks, which are listed in the table below.

Task-Nr.	Task	Task Leader
1.1	Integrated optics modules optimised for 780nm	UNOTT
1.2	Micro-integrated diode lasers for cold atom applications	FBH
1.3	Integration of the entire optical system for the iSense sensor	UHH
1.4	Evaluation of GaN integrated optical technologies	Bham
1.5	Review of the technologies to realize visible wavelength diode laser based laser systems, including micro-integrated frequency doubled laser systems	FBH

Task 1.4 and 1.5 are not starting prior to month 12.

Summary of progress towards objectives

DFB Diodes have been tested and show single mode operation or at most experience a single mode hop over the full current tuning range of 400mA. This diode can be operated at high output powers at the wavelength of the Rubidium D2-line, and have a FWHM linewidth of slightly over 1 MHz depending on the injected current, and an intrinsic linewidth of 25 kHz.
Power amplifiers have been processed and characterization will start in the mid of July.
The development phase for the master lasers based on an extended cavity design is finished and first prototyped are expected in the mid of August.
Miniaturized Rubidium gas cells have been tested in Hamburg and delivered to the FBH for integration into the spectroscopy module. The development of the concept for the spectroscopy module for the frequency stabilization of the master laser has been started.
On the fibre coupling side there have been two concepts designed and one of them has already been tested and could reach a maximal fibre coupling efficiency of up to 80%. After these tests a second version has been designed, is currently in the workshop and should be ready for testing in the next weeks.
There have also been tests on fibre coupling on a Zerodur base plate and we could reach a temperature stability of the fibre coupling of less than 1% per °C in the range of 20-35°C.
Furthermore first studies on GaAs/AlGaAs waveguides are carried out and the engineering specifications of an integrated optics device are determined.

The development of the laser system and the fibre coupling is well on time but due to some delays in the processing of the amendments to Annex-I in discussion with the EC and shift of resources for the University of Nottingham, there is a delay of approximately 2 months in the start of the investigation of waveguide structures. However it is anticipated that this delay can be compensated by focussing of resources, such that the first waveguide-related task can be delivered by month 16 as foreseen in Annex-I.

Details for each task

Task 1.1 Integrated Optics Modules optimized for 780nm

First design studies of the GaAs/AlGaAs waveguide are carried out and the engineering specifications of the integrated optics device are determined.

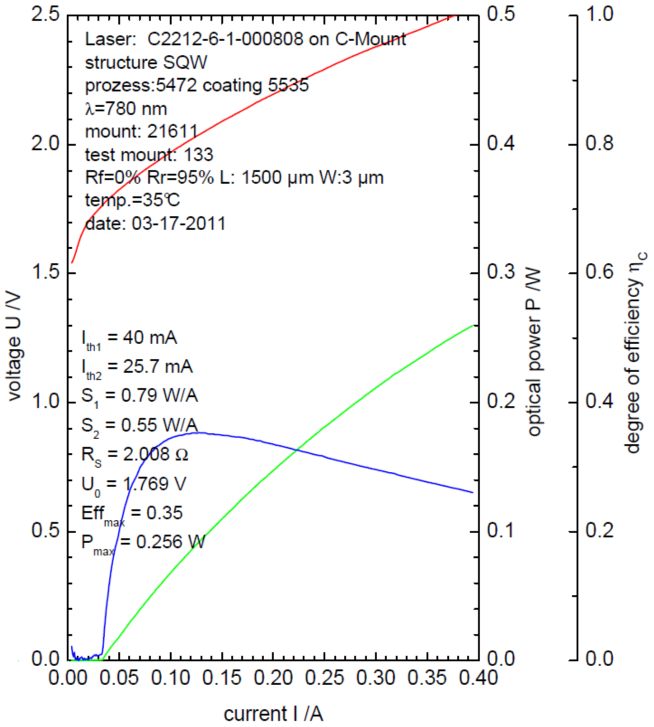
We have also undertaken preliminary computer modelling (i.e. we have set up and successfully run calculations for the geometries required) of the rib wave guides and Mach-Zehnder interferometers needed for on-chip realisation of the laser optics.

Task 1.2 Micro-integrated diode lasers for cold atom applications

(i) DFB-RW lasers

DFB-RW laser were fabricated and tested at the FBH. To characterize these laser diodes the optical output power, the spectrum and the linewidth have been recorded.

Typical characteristics of DFB-Diodes from this charge are illustrated on right side. The measurement of the optical spectrum indicated single mode operation over a current tuning range of 350mA, and it is possible to be operated at the Rb D2-line at a high output power of more than 200mW.



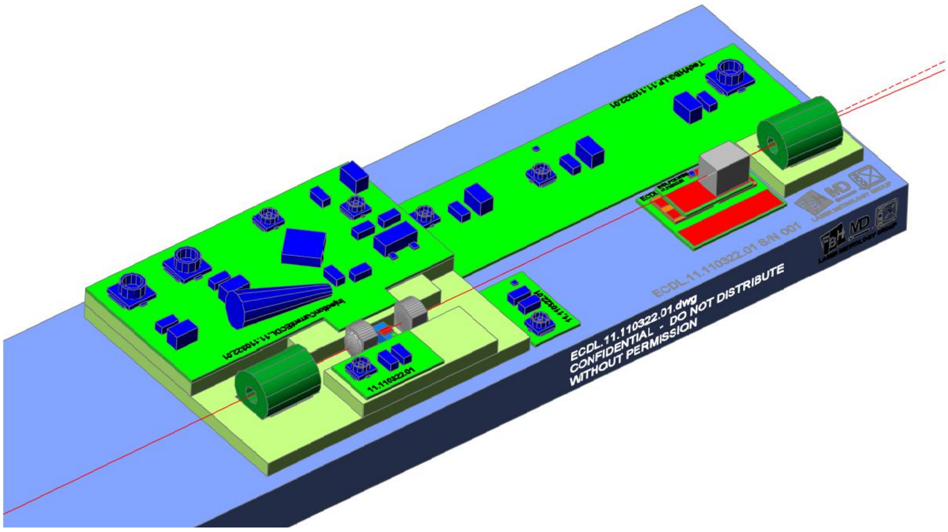
Measurements of the linewidth of the laser diodes revealed a FWHM linewidth of 1.2 MHz and an intrinsic linewidth of 25 kHz.

(ii) Power Amplifiers

Power Amplifiers have been processed and are currently being AR-coated. A characterization of the PA chips will start in the mid of July.

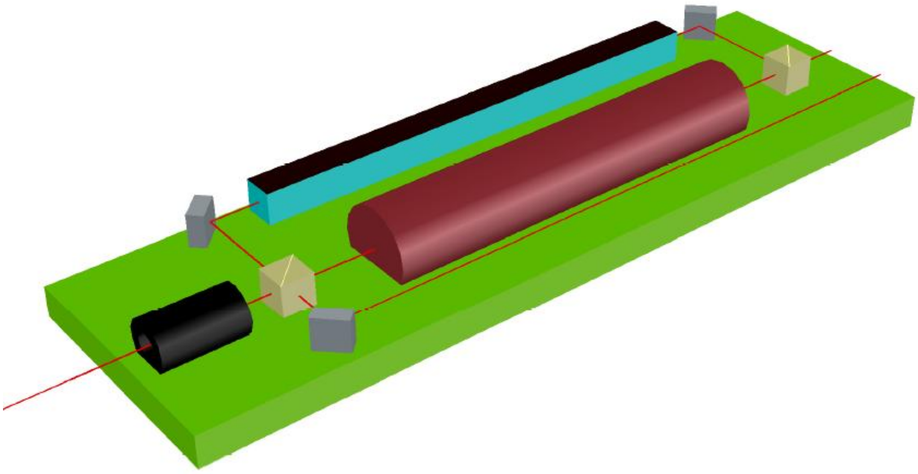
(iii) Extended cavity diode lasers

A design of an extended cavity diode laser is illustrated below. The design includes the laser chip, optics for collimating the output beam, a volume holographic Bragg grating (VHBG) for the feedback, optical isolators, micro peltier elements for temperature control, temperature sensors and the electronic interface, all on a footprint of 25 x 80mm².



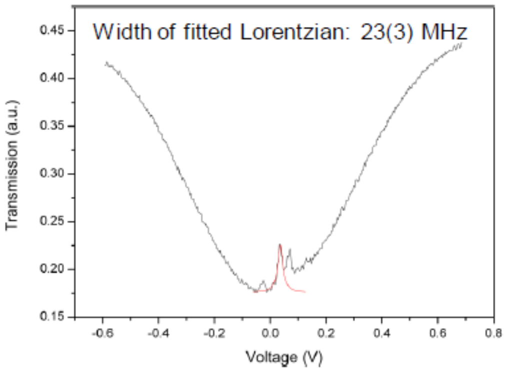
The tuning of the wavelength is done by tuning the temperature of the VHBG.
The electronic interface supports two-section RW laser chips with a gain section and a modulation section. The modulation section allow for a low frequency modulation of up the 10MHz for frequency modulation spectroscopy and also a direct µ-wave modulation of the laser diode for providing multiple frequencies (e.g. for Raman interferometry).
The development phase of these ECDLs is completed and the components are currently being manufactured by an external supplier. Delivery of a first prototype is expected in August 2011.

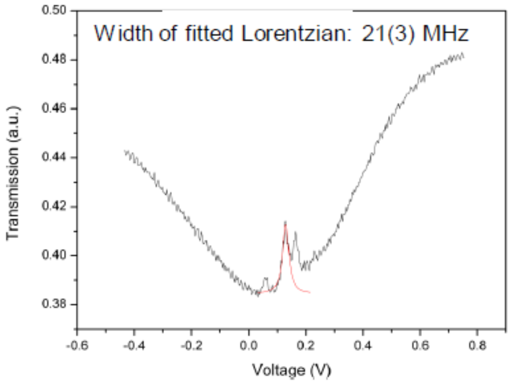
(iv) Rubidium spectroscopy module



For frequency stabilization of the master laser a spectroscopy module is being designed and the concept is depicted above.
It consists of a miniaturized Rubidium gas cell from the UHH, an electro optical modulator, a retarder, photodiodes, optical components for beam guidance and an electronic interface which includes EOM drivers, electronics for photodiodes and a demodulation circuit. So it will be possible to generate the error signal for frequency stabilization directly on this module. Modulation transfer spectroscopy has been chosen as preferred method of stabilization.

(v) Miniaturized spectroscopy cells
Miniaturized spectroscopy cells with a length of 20 mm and a diameter of 5 mm have been tested. These cells are designated to be used in the Rubidium spectroscopy module.





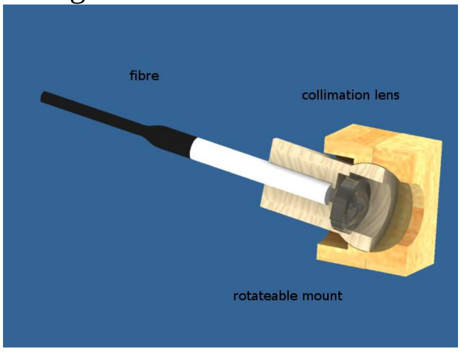
Tests showed that even with these short cells an absorption signal of the D2-line of ^{85}Rb can be obtained. Depicted above are the obtained error signals with a normal sized spectroscopy cell (length: 100mm, diameter: 25mm) on the left side, and a miniaturized one on the right side.
Additionally it was possible to stabilize a laser on an atomic transition by using one of the miniaturized spectroscopy cells.

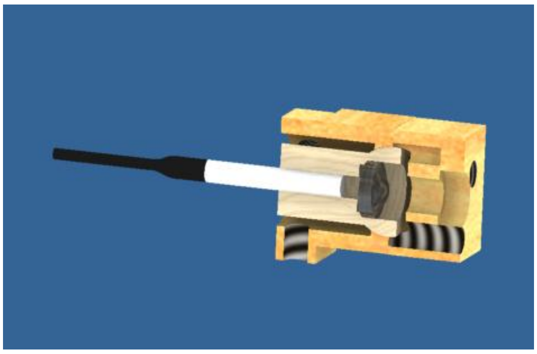
Task 1.3 Integration of the entire optical system for the iSense sensor

(i) Fibre coupling methods

A literature research on different methods for waveguide-to-fibre coupling has been performed and the equipment for the micro-adjustment has been set up. Waveguide-to-fibre-coupling has not yet been explored practically as the first passive waveguide structures are only expected at the beginning of year 2 of the project.

Based on the knowledge on working with Zerodur obtained within the QUANTUS project a first approach on realizing stable fibre couplers were made by designing, fabricating and testing a free space fibre coupler made of Zerodur.
These tests showed a high maximal fibre coupling efficiency of up to 80% for the coupling of light coming out of one fibre into another. But long term tests indicated a stability lower than expected. So another concept has been designed, one that is more relying on screws to keep the fibre in position while gluing.
Both designs are depicted in the pictures below, the first approach on the left and the latter one on the right.

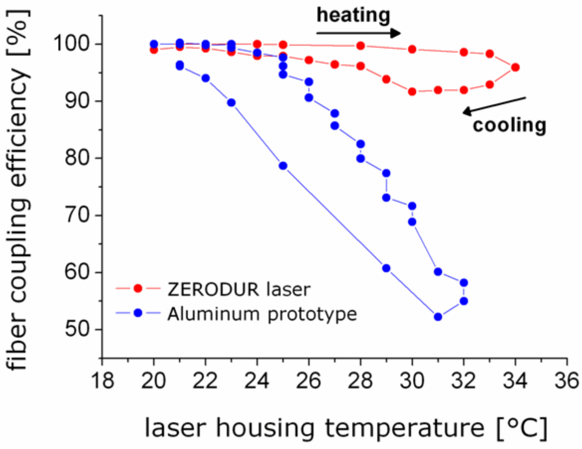




On other coupling methods such as butt-coupling and/or lensed fibres there has been some literature research going on, and work on these other methods will be starting as soon as a waveguide is available.

(ii) Stability of fibre coupling on a low expansion base plate

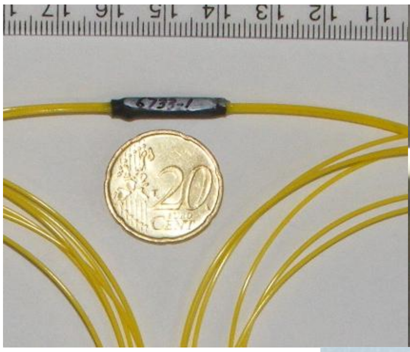
To prepare the integration of the whole system on a low expansion base first tests have been made using a Zerodur based laser module. This module makes use of a Zerodur base plate in combination with a commercially available fibre coupler from "Schäfter+Kirchhoff". To test the temperature stability of this setup the base plate was put on a hot plate and the change of fibre coupling efficiency was observed. And as depicted on the right, the coupling efficiency changed by less than 10% while varying the temperature from 20°C to 35°C and back.



Task 1.4 Alternative free-space optical delivery system

We have started the following work on a fibre-optics based hybrid integrated splitter solution:

- Market research on fibre optics components suitable for iSense. Identified companies for integrated fibre splitters, fibre switches and fibre coupled acousto-optic modulators
- Purchased sample devices for all of the above and started testing them for performance
- Started design work for hybrid fibre splitter solution



Clearly significant results

- The production of narrow-linewidth DFB-RW laser diodes is unique and ensures that iSense technology is at the forefront of technical feasibility.
- The miniaturized spectroscopy cells are a crucial step needed for the micro-integrated laser systems.
- The Zerodur-based baseplate technology is unique for the realisation of active optical systems.

Deviations from Annex I and their impact on other tasks, available resources and planning
NA

Reasons for failing to achieve critical objectives and/or not being on schedule and explain the impact on other tasks as well as on available resources

Due to some delays in the processing of the amendments to Annex-I in discussion with the EC and shift of resources for the University of Nottingham, there is a delay of approximately 2 months in the start of the investigation of waveguide structures. However it is anticipated that this delay can be compensated by focussing of resources, such that the first waveguide-related task can be delivered by month 16 as foreseen in Annex-I. We do not expect any significant impact on other tasks or the project as a whole.

Statement on the use of resources, highlighting and explaining deviations between actual and planned person-months per work package and per beneficiary in Annex 1
Except for some delay as explained above in hiring a researcher to work on waveguide processing the use of resources is in general agreement with Annex-I.

WP 2- *Science Chamber and Scheme*
Work package leader: CNRS-SYRTE

Introduction

The overall objective of this work package is to establish and optimize the technological steps necessary to realize a guided atomic quantum sensor, in which atoms are either trapped in optical lattices or levitate thanks to sequences of laser pulses. The feasibility of this technology for gravity sensing will be demonstrated, a small scale (< 1liter) vacuum chamber and an adapted low power atom chip developed. The work will be carried out keeping two main constraints into account: the physical principle has to operate in a reduced volume, the chosen species for the technology demonstrator is Rb. In addition we will lay the foundations to broaden the iSense platform to include further species, which are in particular interesting as optical time and frequency standards or for quantum information applications. Particular attention will be devoted on the evaluation of performances of interferometric schemes applied on alkali-earth species in comparison with alkali atoms.

The work package is organised by subdivision in four tasks, which are listed in the table below.

Task-Nr.	Task	Task Leader
2.1	Interferometer scheme	CNRS-SYRTE
2.2	Low power atom chip	UNOTT
2.3	Small scale vacuum chamber	CNRS-IOGS
2.4	Alternative atoms and schemes for future sensors	UNIFI

Summary of progress towards objectives

Demonstration of a Ramsey type Wannier Stark interferometer, with preliminary sensitivity of $6\ 10^{-5}$g at 1s

- Comparison between lattice amplitude and phase modulation schemes, coherence time larger than 28s
- Study of dephasing effects in levitation scheme

- Definitive results of glass-glass connections based on silicate bounding : the resulting assembly does not comply with the required mechanical specifications
- Study of alternative design based on gluing a glass cell on a metal flange

- Optimized production of 84Sr BEC with up to $4\text{x}10^6$ atoms at IQOQI-OEAW
- Detection and manipulation of nuclear spin states of 87Sr at IQOQI-OEAW
- Operation of a Sr 3D-MOT on the $^1S_0$-$^1P_1$ transition at 461 nm at UNIFI
- Yb 2D-MOT system setup completed at UHH

The preliminary results indicate that the target sensitivity of 10 μgal/$\text{Hz}^{1/2}$ is out of reach for the present implementation of the bouncing gravimeter, both considering the classical and the quantum one. The reported sensitivity in the proof-of-concept experiment is $\delta g/g \sim 10^{-4}/\text{Hz}^{-1/2}$, or four orders of magnitude from the targeted one.

With some improvements a scale up of 1 or 2 orders of magnitude can be foreseen.

An alternative way to realize the mirrors has been proposed in Phys. Rev. A **80**, 031602 (2009): it uses Raman transitions to implement a multiple paths levitated interferometer.

The results of the tests conducted on glass/glass and glass/metal are absolutely not satisfactory.

As for the glass to metal interface, feasible and already experimented alternative solutions are under consideration. This does not have important impact on other tasks, since the solutions envisaged comply with the sensor requirements (compactness, weight, robustness, optical access).

Details for each task;

Task 2.1 Interferometer scheme

(i) Wannier-Stark interferometer scheme
So far the investigations at CNRS-SYRTE have delivered the following results:

- Demonstration of a Ramsey type WS interferometer, with up to 50% contrast for T=400 ms
- Best relative sensitivity on the measurement of the Bloch frequency : 6 10^{-5} at 1 s
- Investigation of noise sources
- Frequency locking of the lattice laser
- Modification of the Raman laser system
- Calculation of the energy levels and the metastable states of an atom trapped in a vertical optical standing wave (Wannier-Stark states)
- Model of the modification of these energy levels and states in presence of a surface taking into account the Casimir-Polder effect in proximity of it
- Investigation of the shifts produced by a hypothetical Yukawa-type gravitational potential and discussion on their experimental observability

(ii) Modulation scheme
So far the investigations at UNIFI have delivered the following results:

- Experimental comparison between phase modulation and amplitude modulation to induce resonant tunneling of Sr atoms in an optical lattice.
- Detection of resonance tunneling spectra with Fourier limited resolution up to the fifth harmonic
- Demonstration of reversible coherent transport with amplitude-modulation induced tunneling
- ~ 28 s lower limit to coherence time, limited by background gas collisions
- application of resonant phase modulation of lattice for narrowing the atomic momentum distribution
- Investigation of main sources of decoherence

(iii) Levitation scheme
So far the investigations at CNRS-IOGS have delivered the following results:

- Analysis of the multiple order diffraction paths presented in EPL 89 10002 (2010), considering the contributes of the sets of trajectories with equal phase contribution; this allows to interpret the switch between the classical and quantum regime, and for the latter to quantitatively describe the narrowing and deformation effect of the fringes as a function to the number of bounces.
- Study of the dephasing effects, related to the power amplitude fluctuations of the Bragg mirrors, as well as to the presence of interfering paths with phase contributions incommensurable to that given by the single high-order diffraction contribute. The last effect poses a limits on the maximum number of bounces, and thus to the achievable precision.

CNRS-IOGS has been able to deduce the following preliminary conclusions:

- The preliminary results indicate that the target sensitivity of 10 μgal/Hz$^{1/2}$ is out of reach for the present implementation of the bouncing gravimeter, both considering the classical and the quantum one. The reported sensitivity in the proof-of-concept experiment is $\delta g/g \sim 10^{-4}/Hz^{-1/2}$, or four orders of magnitude from the targeted one.
- Several improvements can be implemented: a power stabilization for the diffraction beams; pulse shaping to optimize the diffraction amplitude of the interfering paths; adopt a colder atomic source to increase the number of bounces. With these improvements a scale up of 1 or 2 orders of magnitude can be foreseen.
- A further improvement of the sensitivity will require to adopt a lighter atom for the levitation: this will increase the period associated to the classic trajectory (which narrows the interfringe by the mass ratio); reduce the effect of the initial energy distribution, since the recoil energy associated to the reflection is bigger (this means a reduction of the atom loss during the sequence). Changing the atomic species is not viable on the present setup.
- An alternative way to realize the mirrors has been proposed in Phys. Rev. A 80, 031602 (2009): it uses Raman transitions to implement a multiple paths levitated interferometer.

Task 2.2 Low power atom chip

We have designed, constructed and tested an integrated platform for laser cooling of Rb-87 near a reflecting atom chip. We were able to produce all magnetic fields needed with Cu wire structures that are integrated into the chip mount and have corss sections of a few mm^2. Their overall size is a few cm^3, we dissipate less than 5W in the working model, but at the moment at currents in excess of 100A. After consultation with other iSense members a second generation design was started that is aimed at <20A and similarly low power consumption. With the working model, we will attempt magnetic trapping and evaporative cooling. The new design for a second generation low power atom chip under structure is finished including a systematic consideration of the design parameters and calculations of the produced trapping field.
The design for the second generation under structure consists of a single current carrying sheet of copper, with a periodically varying width as shown in the figure below.

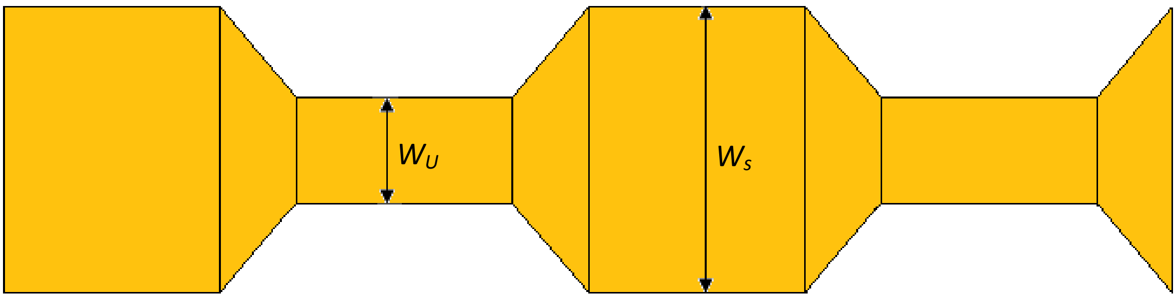


Figure. Two complete layers of the second generation under structure before winding. The sheet can be replicated as many times as desired to produce more layers.

By considering the effects of altering the different parameters the field was decided to be optimal when w_S=44mm, w_U=5mm, h_B=10mm, n_L=20 and I=20A. These values were chosen to produce a field minimum which was as far away from the surface of the chip as possible whilst maintaining steep enough trapping gradients. The U bar width was first set to be as wide as possible whilst remaining in the region where the effects of its width and height first become apparent. This allowed for the benefits of a using a wide sheet to start to become apparent in the shape of the field whilst the strength of a field produced by in infinitely small wire remained. The width of the current sheet was then manipulated until 4.5<r_T<6.5mm and then further adjusted until the field gradients had a magnitude exceeding 10G/cm in each direction. The separation between the sheets was then finely tuned to give the best highest gradient strength to r_T ratio. The figure below shows the quadrupole field that would be produced in the xy plane using these parameters when the side wire current is set to zero.

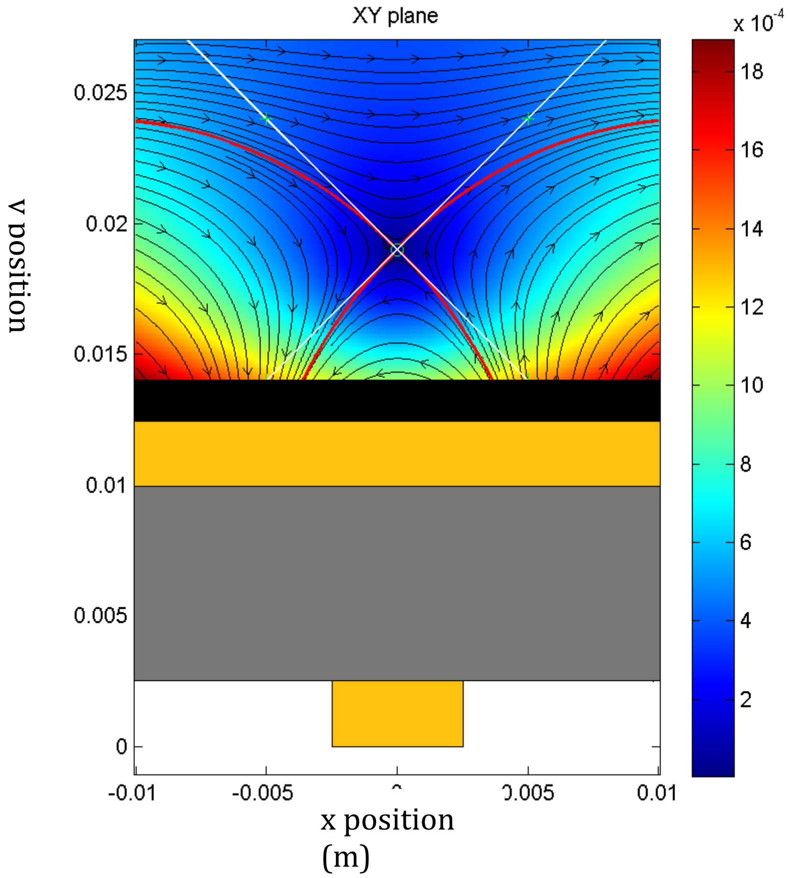


Figure. The field produced in the xy plane when w_S=44mm, w_U=5mm, h_B=10mm, n_L=20 and I=20A. The low and high gold blocks show the size and position of the current sheet and the U bar respectively and the grey area represents the insulting block. It should be noted that the width of both the current sheet and the block extend further than the edges of the figure. The black area represents the space between the under structure and the chip surface which would be along the surface of the black area. The green circle shows the position of the minimum of the field and the red lines show the axis of the quadrupole. The white lines run at 45^o to the surface of the chip and show the laser beam paths, the green +'s show the distance along these axis that the acceptable field distance extends. The colour bar scale is in Tesla.

The field has a minimum 5mm above the chip surface at y = 19mm and x = 0. The trapping gradients in the x' and y' directions have a magnitude of 11.39 G/cm and the acceptable field distance is 7.07mm. This quadrupole has large enough gradients and a large enough acceptable field distance to meet the minimum criteria desired for the second generation under structure. The z direction confinement is created with a side wire, which was also optimised.

The second generation chip is now under production and the design process for an optimized under structure was started.

Task 2.3 Small scale vacuum chamber

Tests have been conducted on the feasibility of vacuum systems based on glass/glass connections using silicate bonding. The definitive results is that the resulting assembly does not comply with the required mechanical specifications, especially concerning the resistance to bending stress during the screwing operation of the glass part to the metal one. The vacuum cells broke even using very soft gaskets (annealed ductile copper or indium), and before we could reach the UHV regime (better pressure 10^{-5} mbar). We cannot asses then the limit vacuum pressures for the silicate bonding.
We started considering alternative designs, where a glass cell is glued on a metal flange. Two alternative approaches are studied: one consists in realizing a hole in the flange where to fit the cell (required machining precision 1/10 to 1/100 mm), and filling the gap with UHV-compatible glue (e.g. UHVGLUE-H77 from Caburn-MDC has been tested below 10^{-10} mbar). The second approach consists in using a commercial metal to glass adaptor (e.g. FGA-025-2 from Caburn-MDC) and a high quality glass cell. The last solution has been implemented with success in the group of P. Treutlein, where one face of the cell even consists of the glued atom chip.
The results of the tests conducted on glass/glass and glass/metal are absolutely not satisfactory. Feasible and already experimented alternative solutions are under consideration. This does not have important impact on other tasks, since the solutions envisaged comply with the sensor requirements (compactness, weight, robustness, optical access).

Task 2.4 Alternative atoms and schemes for future sensors

UNIFI:

- Optimization of SHG for the 461 nm laser source ($^1S_0$-$^1P_1$).
- Optimization of transverse cooling of the atomic beam.
- Laser system at 461 nm locked to the $^1S_0$-$^1P_1$ transition via fluorescence spectroscopy in the transverse cooling region.
- Operation of Zeeman slower.
- Operation of 3D-MOT on the $^1S_0$-$^1P_1$ transition at 461 nm.

UHH:

- Spectroscopy beam apparatus on-line.
- Laser system at 399 nm locked to the $^1S_0$-$^1P_1$ transition via fluorescence spectroscopy at the beam apparatus
- Photomultiplier for detection of fluorescence on the $^1S_0$-$^1P_1$ transition installed.
- 2D-MOT system setup completed.
- Active cooling of the 2D-MOT coils allows for field gradients exceeding 50 G/cm.
- Vapour detected in 2D-MOT cell via fluorescence confirmed functionality of dispenser sources in the 2D-MOT configuration.

IQOQI-OEAW:

Optimized production of ^{84}Sr BEC. We have produce ^{84}Sr BECs with $4x10^6$ atoms, 25 times the atom number of our first Sr BECs. Essential ingredients for this improvement were: a pancake shaped large volume dipole trap, increased stability and accuracy of the intercombination line laser, and an improved dipole trap loading scheme. The production of ^{84}Sr BECs with large atom number provides a solid foundation for future research with this isotope and also improves the starting point for the production of isotopic or elemental mixtures with ^{84}Sr.

Detection and manipulation of nuclear spin states of ^{87}Sr. We have implemented two complementary methods to characterize the nuclear spin state mixture of an ultracold cloud of ^{87}Sr: optical Stern-Gerlach state separation and state-selective absorption imaging. These methods have been used to prepare a variety of spin-state mixtures by optical pumping and to measure an upper bound of the ^{87}Sr spin relaxation rate. Spin state detection and manipulation is essential for any application of ^{87}Sr.

Mott insulator of ^{84}Sr. We have implemented an optical lattice and observed the superfluid to Mott-insulator transition with ^{84}Sr. The Mott insulator of ^{84}Sr will be the starting point for numerous studies ranging from the characterization of Sr properties, the implementation of quantum simulations with Sr, to the production of RbSr ground-state molecules.

Our increased skillset in handling Sr will increase the design space of future Sr interferometers and help us to characterize properties of Sr relevant for iSense.

Clearly significant results

- All interferometer schemes have been demonstrated and first evaluations have been performed. The indication that the Levitation scheme is likely to miss the iSense sensitivity targets is an important input for the further planning of activities towards scheme selection.
- A low-power “stand-alone” atom chip has been demonstrated, underlining the feasibility of the iSense approach and being a key step towards low power consumption of the entire system.
- Manipulation and precision measurement methods for Sr have been developed to a high standard.

Deviations from Annex I and their impact on other tasks, available resources and planning
NA

Reasons for failing to achieve critical objectives and/or not being on schedule and explain the impact on other tasks as well as on available resources
There is a slight delay of roughly 2 months in the work towards demonstrating laser cooling in the Yb earth alkali apparatus. By the time of writing this report, the experiment was well on the way of catching up and we do not foresee any implications for other tasks.

Statement on the use of resources, highlighting and explaining deviations between actual and planned person-months per work package and per beneficiary in Annex 1
The use of resources is in general agreement with Annex-I.

WP 3- *Integrated Sensor*

Work package leader: Bham

Introduction

The overall objective is to demonstrate the iSense technology platform in a proof-of-principle instrument and to include all electronic modules needed to operate and control the lasers, mag-netic field coils, and other components. The particular instrument chosen is an optical lattice based cold atom gravity sensor, which will bring together all aspects of the technology platform and all expertise generated.

The work package is organised in two tasks, which are listed in the table below.

Task-Nr.	Task	Task Leader
3.1	Electronics	LUH
3.2	Integrated gravity sensor	Bham

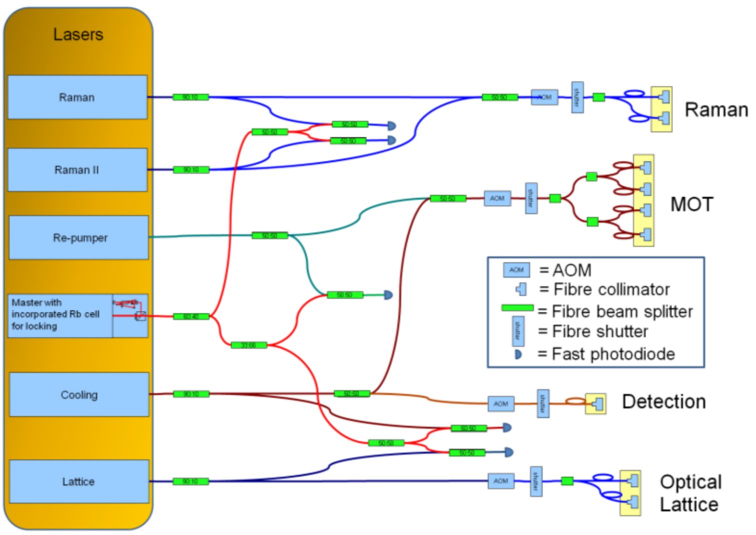
Summary of progress towards objectives and details for each task;

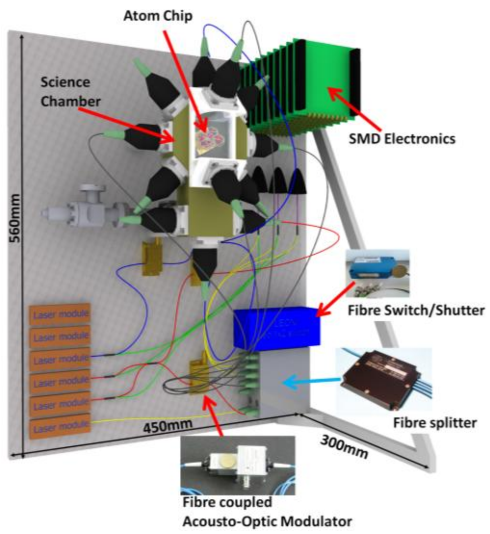
Task 3.1 Electronics

- The development of an electronic module for switching components like ventilators is finished. This allows the iSense gravimeter instrument to have the ventilation on only during non-critical times.
- The development of a dual high current driver for tapered amplifiers is finished. This module can deliver up to 3 A of current.
- The development of the dual temperature controller is finished. This module can stabilize up to 2 lasers. It connects to 4 NTC temperature sensors (2 stabilized, 2 auxiliary) and 2 peltier elements.
- The development of a NTC & photodiode input module is finished. This module is for housekeeping and diagnostic purposes. It has 25 channels and a resolution of 16 bits.

Task 3.2 Integrated gravity sensor

We initialized a full system design including laser system, optical system, electronics, science chamber, atom chip and mounting hardware, which will be an evolving work document taking developments and new knowledge into account until the final design is to be fixed by month 24 of the project. The current design status is:





Clearly significant results
Overall the sensor design is progressing well. The most significant result so far is that there have not been any major obstacles occurring.

Deviations from Annex I and their impact on other tasks, available resources and planning
NA

Reasons for failing to achieve critical objectives and/or not being on schedule and explain the impact on other tasks as well as on available resources
NA

Statement on the use of resources, highlighting and explaining deviations between actual and planned person-months per work package and per beneficiary in Annex 1
Due to a delay in hiring a PhD student at Bham, the man months from this side are slightly lower than planned, however the main activities on the integrated sensor in WP3 are still to come with first parts being delivered from other partners in the next year. This is in part compensated by a postdoc hired with Bham resources, who has spent 3 months on the project so far. A student has been hired 1.July 2011, such that the cumulative man-month over the project will be in line with the planning.
Otherwise the resources are in general agreement with Annex-I.

WP 4 - *Dissemination*

Work package leader: LUH

Introduction

The objectives of this workpackage are:

• Dissemination of the project results to partners outside the consortium

• To make the scientific, professional and general public aware of the iSense project and its plans, results and potential benefits that can be derived from S&T achievements

• To attract additional RTD funds in order to make the iSense consortium operational and prosperous after the end of the project.

The work package is organised in seven tasks, which are listed in the table below.

Task-Nr.	Task	Task Leader
4.1	Communication tools	LUH
4.2	iSense film	LUH
4.3	Outreach campaigns and education	LUH
4.4	Contribution to portfolio and concertation activities at FET-Open level	Bham
4.5	Marketing	LUH
4.6	Sensor deployment	Bham
4.7	Use and dissemination of foreground	Bham

Summary of progress towards objectives and details for each task;

Task 4.1 Communication tools

completed, maintenance & updates remaining

Task 4.2 iSense film

Pending (planned for month 24-36)

Task 4.3 Outreach campaigns and education

Workshop is in Preparation, timeslot determined (9.-12.06.2012) desired Speakers identified, Invitations pending

Task 4.4 Contribution to portfolio and concertation activities at FET-Open level

A webpage was created as a platform to disseminate project results to the general public.

The iSense project was represented by K. Bongs and P. Bouyer using a Poster and personal discussion at the FET11 conference 4th-6th May 2011 in Budapest. The discussions have led to 7 new cross-disciplinary contacts, with the intention to initiate future international collaborations related to the iSense project. These contacts have all been followed up by e-mail. One contact with the Glasgow Centre for Nanoscience led to a visit including further discussion and a seminar by Prof. Charles Ironside from the School of Engineering at the University of Glasgow on the 29th July 2011.

In addition there has been a good number of publications and conference presentations related to iSense, as listed in section 5.

Task 4.5 Marketing

Pending (planned for months 24-48)

Task 4.6 Sensor deployment
Pending (planned for months 42-48)

Task 4.7 Use and dissemination of foreground
Pending

Clearly significant results
See publications in section 5

Deviations from Annex I and their impact on other tasks, available resources and planning
NA

Reasons for failing to achieve critical objectives and/or not being on schedule and explain the impact on other tasks as well as on available resources
NA

Statement on the use of resources, highlighting and explaining deviations between actual and planned person-months per work package and per beneficiary in Annex 1
The resources are in general agreement with Annex-I

4. Deliverables and milestones tables

Deliverables (excluding the periodic and final reports)

TABLE 1. DELIVERABLES									
Del. no.	**Deliverable name**	**WP no.**	**Lead beneficiary**	**Nature**	**Dissemination level**	**Delivery date from Annex I (proj month)**	**Delivered Yes/No**	**Actual / Forecast delivery date**	**Comments**
4.1	Project Website	4	LUH	others	public	6	yes	6	Please see http://www.isense-gravimeter.com/

Milestones

TABLE 2. MILESTONES							
Milestone no.	**Milestone name**	**Work package no**	**Lead beneficiary**	**Delivery date from Annex I**	**Achieved Yes/No**	**Actual / Forecast achievement date**	**Comments**
MS6	Web page online	4	6 (LUH)	6	yes	6	http://www.isense-gravimeter.com/

5. Project management

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

Management tools

Management of the consortium involves several mechanisms. Each participant is required to provide the respective workpackage 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 workpackage prodiced by the respective workpackage leader. They summarize the preceding three months' of research and in particular highlight if the workpackage 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 workpackages.

The project coordinator holds meetings with individual workpackage 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 workpackages 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 comittee. In addition some workpackages involving several sites have individual meetings as required to keep the workflow going smoothly (e.g. WP1). Overall, there have been ~30 such meetings in the first year of the project.

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.

Research coordination visits between partners

Date (from and to)	Visiting partner	Visited Partner	Number travelling
22/10/2010	UNOTT	FBH	1
16-17/11/2010	LUH, UHH	FBH	2
19/11/2010	Bham	CNRS	1
22/11/2010	UNOTT	FBH	1
24-26/02/2011	Bham,UHH	UNIFI	2
03/03/2011	LUH	FBH	1
22-24/03/2011	Bham, FBH, LUH	UHH	4
15/04/2011	Bham	CNRS	1
04/05/2011	LUH	FBH	1
06/06/2011	LUH	FBH	1
08-09/06/2011	LUH	FBH	1
27-28/06/2011	Bham, FBH, LUH	UHH	6

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, QUANTUS, SAI, ICE and SOC 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.

- ***Problems which have occurred and how they were solved or envisaged solutions;***
  At the beginning of the project partner QinetiQ has performed an internal restructuring, which lead to closing down their Emerging Technology group which was central to their participitation in iSense. As they did not start their assigned tasks and removed all capability to do so the project steering committee had to declare them in breach of the grant agreement and requested their removal from the project team by the EC. Their participitation was effectively terminated by month 6 of the project. This process lead to a redistribution of tasks and adaptation of Annex-I of the project, to the version dated from 4. March 2011. The consortium has performed a careful evaluation of the internal and external potential to take over the tasks of partner QinetiQ including a critical review of the current state-of-the-art of integrated optics technologies. The results were that although many interesting integrated optics technologies are currently under development, none of them can yet provide the power handling and amplitude modulation capabilities required by iSense. Together with experts from QinetiQ, the University of Nottingham was identified as having the manufacturing and design capabilities to take over the tasks of QinetiQ, although with a slight shift in the workplan timing caused by the delayed start. In order to maintain the time plan for all other work packages and to mitigate development risks it was decided to pursue an additional connector-compatible hybrid optical-fibre/acousto-optical modulator splitter solution at the coordinating institution. This solution will allow to start the work on laser system and sensor integration while the fully integrated GaAs splitter is still under development and to keep the overall project synchronized. The respective resources were freed by shifting the work on GaN waveguide technology beyond the duration of the project.

- ***Changes in the consortium, if any;***
  As discussed above partner QinetiQ was removed from the consortium and its tasks taken over by the University of Nottingham and the University of Birmingham.

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

Date	Venue	Purpose	N attending
13/7/2010	Teleconference	Kick-off and debrief	12
6/10-7/10/2010	Birmingham	Interface Workshop and STEM meeting	16
30/11/2010	Teleconference	STEM-meeting, declaration of QinetiQ to be in breach of grant agreement and discuss redistribution of tasks	11
24/5/2011	Teleconference	Integration	14

- ***Project planning and status;***
  The project is meeting its scientific goals, and has hit all the Milestones to date. Following the review meeting there will be a meeting to plan integration once more late in 2011, a meeting of the STEM will be needed Feb or March 2012, and a summer school together with the Geodesy community is planned to take place in Bad Honnef in summer 2012.

- ***Impact of possible deviations from the planned milestones and deliverables, if any;*** The impact of the restructuring and termination of partner QinetiQ as discussed above has been addressed by redistributing tasks and amending Annex-I to the version dated March 4th 2011, which this report is referring to. The project is in line with this Annex-I.

- ***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. Stellmer, M. K. Tey1, R. Grimm and F. Schreck, Bose-*Einstein condensation of ^{86}Sr,* Phys. Rev. A 82, 041602(R) (2010); http://lanl.arxiv.org/abs/1009.1701
2. R. Messina, S. Pelisson, M.-C. Angonin, and P. Wolf, *Atomic states in optical traps near a planar surface*,
Phys. Rev. A 83, 052111 (2011); http://lanl.arxiv.org/abs/1103.1581
3. Q. Beaufils, G. Tackmann, X. Wang, B. Pelle, S. Pélisson, P. Wolf and F. Pereira dos Santos, Laser controlled tunneling in a vertical optical lattice,
Phys. Rev. Lett. 106, 213002 (2011); http://lanl.arxiv.org/abs/1102.5326
4. S. Stellmer, R. Grimm and F. Schreck, *Detection and manipulation of nuclear spin states in fermionic strontium*, http://arxiv.org/abs/1108.2807

Proceedings

1. B. Pelle, G. Tackmann, Q. Beaufils, X. Wang, A. Hilico and F. Pereira dos Santos, S. Pélisson, R. Messina, M.-C. Angonin and P. Wolf, *Forca-G: a trapped atom interferometer for the measurement of short range forces*, Proceedings of the Rencontres de Moriond and GPhys Colloquium, 2011
2. M. de Angelis, M. C. Angonin, Q. Beaufils, Ch. Becker, A. Bertoldi, K. Bongs, T. Bourdel, P. Bouyer, V. Boyer, T. Fernholz, M. Fromhold, W. Herr, P. Krüger, Ch. Kürbis, C. Mellor, F. Pereira Dos Santos, A. Peters, N. Poli, M. Popp, M. Prevedelli, E. M. Rasel, J. Rudolph, F. Schreck, K. Sengstock, F. Sorrentino, S. Stellmer, G. Tino, T. Valenzuela, T. Wendrich, A. Wicht, P. Windpassinger, P. Wolf*; iSense: a portable ultracold-atom-based gravimeter;* FET11 conference proceedings, Elsevier 2011

Conference/Workshop talks

1. F. Pereira Dos Santos, Q. Beaufils, X. Wang, S. Pélisson, M.-Ch. Angonin, P. Wolf, R. Messina, A. Lambrecht, *Un interféromètre à atomes guidés pour des mesures de forces à faible distance*, PAMO 2010, Orsay, France, 29 June-02 July 2010.
2. G. Tackmann, Q. Beaufils, B. Pelle, X. Wang, S. Pélisson, M.-Ch. Angonin, P. Wolf and F. Pereira dos Santos, *Trapped atomic accelerometer for short range*

measurements, Young Atom Opticians Conference (YAO) 2011, Hanover (Germany), 11-19 February 2011.

3. G. Tackmann, Q. Beaufils, B. Pelle, X. Wang, S. Pélisson, M.-Ch. Angonin, P. Wolf and F. Pereira dos Santos, *Trapped atomic accelerometer for short range measurements*, Frühjahrstagung der Deutschen Physikalischen Gesellschaft 2011, Dresden (Germany), 13-18 March 2011.
4. F. Schreck, *Double-degenerate Bose-Fermi mixture of strontium*, APS March Meeting, Dallas, TX, USA, March 21-25, 2011.
5. B. Pelle, Q. Beaufils, G. Tackmann, X. Wang, A. Hilico and F. Pereira dos Santos, S. Pélisson, R. Messina, M.-Ch. Angonin and P. Wolf, *Forca-G : A trapped atom interferometer for the measurement of short range forces*, Gravitational Waves and Experimental Gravity, Rencontres de Moriond and GPhyS Colloquium, La Thuile, 20 - 27 March 2011
6. F. Schreck, *Quantum Degenerate Strontium*, IFRAF-Fermix Meeting, E.N.S., Paris, France, April 13-15 2011.
7. P. Bouyer, *Heterodyne non-demolition measurements on cold atomic samples*, Quantum Science and Technologies Workshop, Rovereto, Italy, 8-12 May 2011.
8. F. Schreck, *Quantum Degenerate Strontium*, Fermions from Cold Atoms to Neutron Stars: Benchmarking the Many-Body Problem, INT, Seattle, USA, 16 - 20 May 2011.
9. T. Vanderbruggen, *Nondestructive measurements and all-optical Bose-Einstein condensation in a high-finesse cavity* , ICOLS Student Workshop, Hannover, Germany, June 2011.
10. F. Schreck, *Quantum Degenerate Strontium*, Gordon Research Conference an Atomic Physics, West Dover, VT, USA, , June 26- July 1, 2011.

Conference/Workshop posters

1. B. Pelle, Q. Beaufils, G. Tackmann, X. Wang, S. Pelisson, M.-Ch. Angonin, P. Wolf and F. Pereira dos Santos, *Forca-G : from a trapped atom interferometer to the measure of Casimir-Polder force and an eventual deviation of Newton's law*, Young Atom Opticians Conference (YAO) 2011, Hanover (Germany), 11-19 February 2011.
2. K. Bongs, T. Valenzuela and Y. Singh, *STE-QUEST & Cold atoms in space*, UK Space Agency Microgravity Workshop, Harwell Oxford, UK, 14-15 March 2011.
3. K. Bongs, T. Valenzuela and Y. Singh, *STE-QUEST & Cold atoms in space*, Fundamental Physics at Low Energies, Durham, 5th-7th April 2011
4. V. Boyer, T. Valenzuela and K. Bongs for the iSense Consortium, *iSense: a portable ultracold-atom-based gravimeter*, FET11 conference, Budapest, Hungary, 4-6 May 2011.

6. Explanation of the use of the resources

TABLE 6.1 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 1 FOR THE PERIOD			
Work Package	Item description	Amount	Explanations
1,2,3,4,5	Personnel costs	*10,906 €*	*Salaries of two permanent staff, Dr Vincent Boyer and Prof Kai Bongs working in total 1.7 man months.*
	Subcontracting	*0 €*	
1,2,3,4,5	Equipment'	*1,153 €*	*Depreciation over 36 months on:* *Hexapod 6-axis parallel kinematics microrobot with 6D hexapod controller;* *1HT101820 HONEYCOMB TABLE TOP 1000;* *Pneumatic vibration isolation system;*
1,2,3,4,5	Consumable	*3,586€*	*Electronic components, catering for project meetings, clamps and lens and accessories for equipment, equipment maintenance,*
	Travel	*1,845€*	*Travel to collaboration workshop in Florence, Italy, 24-26/2/11 T Valenzuela and travel to FET11 conference in Budapest 3-6/5/11 Prof K Bongs.*
	Dissemination	*0€*	
	TOTAL DIRECT COSTS	*17,490€*	

TABLE 6.2 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 2 (QINETIQ – LEFT THE PROJECT) FOR THE PERIOD			
Work Package	Item description	Amount	Explanations
	TOTAL DIRECT COSTS	0	

TABLE 6.3 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 3 (UHH) FOR THE PERIOD			
Work Package	Item description	Amount	Explanations
2	Personnel costs	28968 €	Salaries of two doctoral students: –Andreas Bick 9092 € at 2.25 person months (Design of 2D- and 3D-MOT coils, optimization of blue lasers system for Yb MOT operation) –Sören-Erik Dörscher 19876 € at 4.5 person months (Design and setup of green laser system for production of ultracold Yb mixtures; Design of optical traps for Yb mixtures)
2	Equipment	150 €	–Arbitrary Waveform Generator 50MHz RS23, linear depreciation of 5 years beginning Feb. 2011, purchase price 1152 €, Modulation of a diode laser's current to generate sidebands for FM spectroscopy –954P fixed ratio coupler, 50/50 @ 780nm, linear depreciation of 5 years beginning Apr. 2011, purchase price 1088 €, Monitoring of fiber coupling efficiencies at two outputs
1	Consumables	360 €	Rubidium Vapor Cell 5x10mm
1,2	Travel	410 €	Attendance for one person, Hannes Duncker, at project meeting in Birmingham 06.10.-7.10.2010 . Breakdown of costs: flight 321 € / hotel 68 € / subsistence 21 €
	TOTAL DIRECT COSTS	29.888 €	

TABLE 6.4 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 4 (CNRS) FOR THE PERIOD			
Work Package	Item description	Amount	Explanations
2,3,4	Personnel costs	130.381,05 €	F. Pereira dos Santos, Cost 26451.64 €, Res., 3.88 M P. Wolf, Cost 28 445.91 €, Researcher, 3.48 Months P. Bouyer, Cost 25 766.00 €, Researcher, 1.90 Months T. Bourdel, Cost 20 204.80 €, Researcher, 3.86 Months A. Villing, Cost 29 512.70 €, Engineer, 3.33 Months
2	Equipment	11.540,00 €	Depreciation of a VERDI Laser, Total cost 57 700,00€, Depreciation over 5 years
2,4	Travel	1.329,70 €	First iSense Meeting, in Birmingham (UK), 6-7 October 2010 Flights 411.78 €, subsistence and accommodation 280.1 € Persons attending : Quentin Beaufils, Franck Pereira dos Santos Moriond Conference, la Thuile (Italy), 20-27 March 2011 Flights 522.32 €, subsistence and accommodation 115.5 € Persons attending : Bruno Pelle, Sophie Pélisson, Riccardo Messina 2 talks and 1 poster presenting work related to the project
	TOTAL DIRECT COSTS	143.250,75 €	

TABLE 6.5 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 5 (UNIFI) FOR THE PERIOD			
Work Package	Item description	Amount	Explanations
2	Personnel costs	29.506,30 €	Salary of 1 Full Professor (Guglielmo Maria Tino) for 2.02 Man Months: 17.553,52 euros. Salary of 1 Temporary Researcher (Nicola Poli) for 3.06 Man Months: 11.952,78 euros.
	Equipment	-	
2	Consumables	1.272,45€	Optics and opto-mechanics for experimental activities in WP2.4
2	Travel	612,41 €	Dr. Nicola Poli, iSense meeting in Birmingham (UK), October 06 – 07, 2010: 612,41 euros (flight: 432,00 euros; hotel: 132,56 euros; subsistence: 7,58 euros; other costs: 40,27 euros).
	TOTAL DIRECT COSTS	31.391,16 €	

TABLE 6.6 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 6 (LUH) FOR THE PERIOD			
Work Package	Item description	Amount	Explanations
3,4	Personnel costs	22193	Manuel Popp, researcher, dissemination administrator – 7 month Michael Senkler, research assistant – 1 month Lisa Tessen, research assistant – 1 month
2	Consumables	113	Spare part
4	Dissemination	504	Frontend hardware for website maintenance License fee for Top Level Domain (webpage)
2,3,4	Travel	1241	E. M. Rasel and T. Wendrich, iSense meeting Birmingham, 06. – 07.10.2010 (564 €) M. Popp, representing iSense at the DPG spring meeting, Dresden, 13. – 18.03.2011 (619 €) M. Popp, iSense meeting, Brussels, 13.–16.09.2011 (air ticket, 58€)
	TOTAL DIRECT COSTS	24051	

TABLE 6.7 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 7 (IQOQI-OEAW) FOR THE PERIOD

Work Package	Item description	Amount	Explanations
2,4	Personnel costs	4686€	Salary of PI (Florian Schreck) for activities directly related to iSense (0.8 man months)
	TOTAL DIRECT COSTS	4686€	

TABLE 6.8 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 8 (FBH) FOR THE PERIOD

Work Package	Item description	Amount	Explanations
1	Personnel costs	31.143,11 €	Salary of 1 postdoctoral student for 12 months
1	Subcontracting	2.585,00 €	SIMS-Analysis
1	Consumables	1.265,33 €	2” Wafer, components and Cu-Plate
1	Travel	159,23 € 893,69 €	Attendance Mr. Kürbis at project meeting in Hannover Attendance Dr. Wicht at project meeting in Birmingham, UK.
	TOTAL DIRECT COSTS	36.046,36 €	

TABLE 6.9 PERSONNEL, SUBCONTRACTING AND OTHER MAJOR DIRECT COST ITEMS FOR BENEFICIARY 9 (UNOTT) FOR THE PERIOD

Work Package	Item description	Amount	Explanations
1	Travel	700	P. Krüger – Travel to FBH Berlin in order to discuss taking over tasks formerly designated to QinetiQ, November 2010 M. Fromhold – Travel to an S&I meeting in Birmingham in order to discuss splitter design work with K. Bongs, February 2011
1	Consumables	6757	Semiconductor processing costs
	TOTAL DIRECT COSTS	7457	

7. Financial statements – Form C and Summary financial report

See NEF

8. Certificates

List of Certificates which are due for this period, in accordance with Article II.4.4 of the Grant Agreement.

Beneficiary	**Organisation short name**	**Certificate on the financial statements provided? Yes / no**	**Any useful comment, in particular if a certificate is not provided**
1	Bham	no	Expenditure threshold not reached
2	QINETIQ	no	Withdrawn
3	UHH	no	Expenditure threshold not reached
4	CNRS	No	Expenditure threshold not reached
4 third party	UPMC	No	Expenditure threshold not reached
5	UNIFI	No	Expenditure threshold not reached
6	LUH	No	Expenditure threshold not reached
7	IQOQI-OEAW	No	Expenditure threshold not reached
8	FBH	No	Expenditure threshold not reached
9	UNOTT	No	Expenditure threshold not reached

Appendix 1 Distribution of Person Months by Partner and Work-package

For ease of reference we include a complete table of the actual and planned person months. The "actual" values include only the months claimed as eligible costs, and do not include considerable additional months paid for by the partners, which are included in the "planned" values. Please note that the "planned" values correspond to the total project duration.

Person-Month Status Table

iSense												
PERIOD 1.7.2010 to 30.6.2011			**TOTALS**	BHAM	UHH	CNRS	UNIFI	LUH	OAEW	FBH	UNOTT
WP1:	**Integrated Laser System**	**Actual WP total:**	**24.62**	0.62						24	
		Planned WP total:	**84**	19	5		2	2		30	26
WP 2:	**Science Chamber and Scheme**	**Actual WP total:**	**28.68**	0.10	6.75	15.95	5.08		0.8		
		Planned WP total:	**211**	3	27	76	45	12	14		34
WP 3:	**Integrated Sensor**	**Actual WP total:**	**7.3**	0.2		0.1		7			
		Planned WP total:	**26**		3	11	4	17		1	1
WP 4:	**Dissemination**	**Actual WP total:**	**26**	0.01		0.4		2			
		Planned WP total:	**16**	3	1	4	1	5	1		1
WP 5:	**Management**	**Actual WP total:**	**0.77**	0.77							
		Planned WP total:	**12**	12							
		Actual total:	**87.37**	**1.7**	**6.75**	**16.45**	**5.08**	**9**	**0.8**	**24**	**0**
Total Project Person-month		**Planned total:**	**349**	**37**	**36**	**91**	**52**	**36**	**15**	**31**	**62**