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Bongs, Kai and Malcolm, Jon and Ramelloo, Clemens and Zhu, Lingxiao and Boyer, Vincent and Valenzuela, Tristan and Maclean, Jessica and Piccardo-Selg, Anton and Mellor, Chris and Fernholz, Thomas and Fromhold, Mark and Krüger, Peter and Hellmig, Ortwin and Grote, Alexander and Dörscher, Soren and Duncker, Hannes and Windpassinger, Patrick and Sengstock, Klaus and Becker, Christoph and Pelle, Bruno and Hilico, Adèle and Zhou, Minkang and Angonin, Marie-Christine and Wolf, Peter and Dos Santos, Franck Pereira and Bertoldi, FranceAndrea and Bouyer, Philippe and Mazzoni, Tommaso and Poli, Nicola and Sorrentino, Fiodor and Tarallo, Marco and Tino, Guglielmo and Stellmer, Simon and Schreck, Florian and Popp, Manuel and Herr, Waldemar and Wendrich, Thijs and Ertmer, Wolfgang and Rasel, Ernst and Kürbis, Christian and Peters, Achim and Wicht, Andreas (2014) iSense: a technology platform for cold atom based quantum technologies. In: Quantum Information and Measurement 2014, 18-20 March 2014, Berlin, Germany.

iSense: A Technology Platform for Cold Atom Based Quantum Technologies

Kai Bongs, Jon Malcolm, Clemens Ramelloo, Lingxiao Zhu, Vincent Boyer, Tristan Valenzuela
Midlands Ultracold Atom Research Centre, Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, UK
Jessica Maclean, Anton Piccardo-Selg, Chris Mellor, Thomas Fernholz, Mark Fromhold, Peter Krüger
Midlands Ultracold Atom Research Centre, School of Physics and Astronomy, University of Nottingham, Nottingham NG7 2RD, UK
Ortwin Hellmig, Alexander Grote, Soren Dörscher, Hannes Duncker, Patrick Windpassinger, Klaus Sengstock, Christoph Becker
Institut für Laser-Physik, Universitat Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany
Bruno Pelle, Adèle Hilico, Minkang Zhou, Marie-Christine Angonin, Peter Wolf, Franck Pereira Dos Santos
LNE-SYRTE, Observatoire de Paris, LNE, CNRS, UPMC, 61 avenue de l'Observatoire, 75014 Paris
FranceAndrea Bertoldi, Philippe Bouyer
Laboratoire Charles Fabry de l'Institut d'Optique, CNRS and University Paris-Sud, Campus Polytechnique, RD 128, 91127 Palaiseau cedex, France
Tommaso Mazzoni, Nicola Poli, Fiodor Sorrentino, Marco Tarallo, Guglielmo M. Tino
Dipartimento di Fisica e Astronomia and LENS, Università di Firenze-INFN Sezione di Firenze, Via Sansone 1, 50019 Sesto Fiorentino, Italy
Simon Stellmer, Florian Schreck
Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, 6020 Innsbruck, Austria
Manuel Popp, Waldemar Herr, Thijs Wendrich, Wolfgang Ertmer, Ernst Rasel
Institut für Quantenoptik, Leibniz Universität Hannover, Am Welfengarten 1, 30167. Hannover, Germany
Christian Kürbis, Achim Peters, Andreas Wicht
Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin,Germany

Abstract: A breakthrough in cold atom quantum technology is hindered by a bottleneck in the supporting technologies. We discuss a cold atom technology platform developed within the European iSense project, aiming at a gravimeter as demonstrator.
OCIS codes: (020.0020) Atomic and molecular physics; (020.3320) Laser cooling; (020.1670) Coherent optical effects

1. Introduction

Ultracold atom experiments provide an exquisite degree of control over matter at the quantum level. Laboratory experiments have proven that these systems allow harnessing quantum mechanics for applications as diverse as quantum simulation, quantum communication, quantum computation, quantum metrology and ultraprecise sensors. However, despite over 30 years of research and very promising proof of principle demonstrations in a laboratory environment, the quantum technology based on cold atoms is still in its infancy. The reason lies in the complexity of the laser, vacuum, magnetic coil, optics and electronic control systems, which present a bottleneck to commercial applications.

The iSense project aims to develop a modular technology platform for cold atoms, consisting of a set of tools and technologies that can be used as basic blocks to build robust and portable devices based on ultracold atoms. An atom interferometric gravimeter in a backpack-sized format was chosen to demonstrate the usefulness of the iSense technology platform. In laboratory experiments, atom interferometers have already proven superior performance as compared to the best commercial absolute gravimeters, making such a device the natural candidate for a quantum technology demonstrator.

2. Microintegrated laser system

In current laboratory experiments on cold atoms the laser and optical systems are the most critical parts in terms of stability and have the greatest potential for miniaturization. In order to maintain some flexibility, the iSense technology platform combines several microintegrated laser modules developed by the Ferdinand Braun Institute für Höchstfrequenztechnik in Berlin FBH with miniaturized optical benches developed by the University of Hamburg. The microintegrated laser modules range from single collimated DFB diode laser or tapered amplifier modules to complex master oscillator power amplifier systems which combine an external cavity diode laser with feedback from a volume holographic Bragg grating with a tapered amplifier including full collimation optics and optical isolation. The latter achieve above 1W of optical power with a linewidth below 100kHz.

The microintegrated laser modules are mounted on miniaturized optical benches which provide mechanical protection, beam splitting, high power optical isolation and fiber coupling into polarization maintaining optical fibers. Thermal and mechanical stability are ensured by proprietary optical mounts and either linear or Zerodur based construction, ensuring high levels of fiber coupling over large temperature ranges.

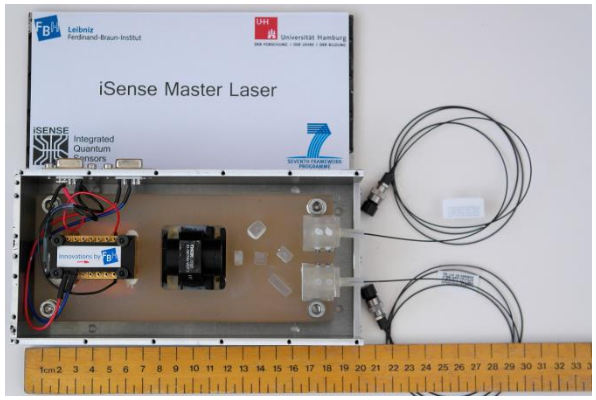

Fig. 1: Microintegrated DFB laser with two output ports.

3. Light distribution

The iSense light distribution system developed at the University of Nottingham aims to develop GaAs / $Al_xGa_{(1-x)}As$ integrated waveguide optics technology to 780 nm to realize a fully integrated waveguide and fiber-based system [1]. The functionality of the polarization-maintaining integrated waveguide systems aims to include efficient fiber coupling, beam splitting, and intensity control. For laser cooling applications the cooling and repumping light will be combined and delivered to a number of output fibers directly connected to the telescopes attached to the science chamber. After optimization of material and growth processes as well as the design of fiber coupling structures towards low-loss operation at 780 nm, a range of test modules were produced which are now under evaluation.

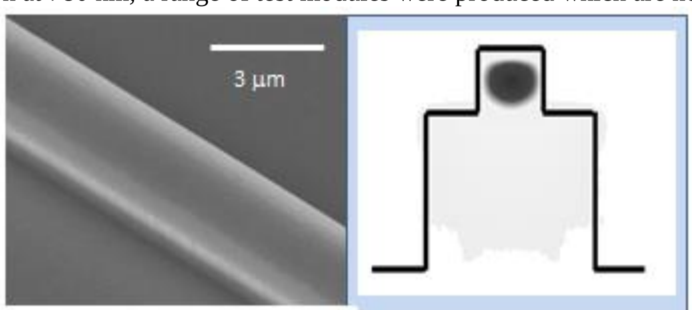

Fig. 2: Scanning Electron Microscopy image (left) of 2.5 μm wide waveguide using Inductively-Coupled Plasma etching SiCl4 / Ar at a substrate temperature of 0°C and simulation (right) using Optiwave of single-mode, polarization-maintaining waveguide in cross-section for 780 nm laser light

The integrated waveguide system will act as a drop-in replacement for a full fiber coupled system composed of a fiber distribution module, fiber AOMs for intensity control and fiber switches, which currently allows parallel optimization of the iSense demonstrator setup.

4. Vacuum system and atom chip

The demonstrator vacuum chamber is manufactured from titanium in order to achieve non-magnetic properties and uses indium-sealing for the windows to reduce stress and weight. The University of Nottingham designed and fabricated a low-power atom chip not needing external coils and mounted on a CF63 flange. The inner volume is 0.7 liters and the total volume of the chamber body (i.e. not including flanges and pumping section) is 1.7l, giving a net weight of 3.4 kg. The atom-chip assembly adds less than 0.2l to the total volume and contributes about 1.2 kg to the total weight.

The pumping section contributes with 0.8l and 3.1kg to the total volume and weight respectively and adds 0.18l to the evacuated volume. Summarizing the vacuum system has an external volume of 3.5l and a weight of 8kg. It has an inner, evacuated, volume of 0.9l.

5. Control electronics

The iSense control electronics consist of a range of modules in roughly PC104 format. In addition to all laser diode current and temperature controllers it includes an ion pump controller, atom chip current drivers, DDS-based AOM controllers, an FPGA based frequency controller and an overall FPGA controller for the experimental sequence. The frequency controller contains everything needed to stabilize one laser on a spectroscopy line (modulation, demodulation, filtering) and up to 3 lasers with frequency offset locking simultaneously and due to the FPGA programming capability and flexibility allows the development of an automatic stabilization method that can stabilize onto any transition without manual assistance to select a specific line, significantly enhancing the reliability of the laser locking system. In addition a compact frequency reference chain operating at 6.8 GHz was developed, based on an integrated PLDRO (Phase Locked Dielectric Resonator Oscillator).

6. Conclusion and outlook

The complete laser cooling setup for the iSense project has been assembled as shown in Fig. 3. In the final stage, the entire system will be mounted within a 0.5 x 0.5 x 0.5 m^3 volume indicated by the grey compensation coils in fig. 3.

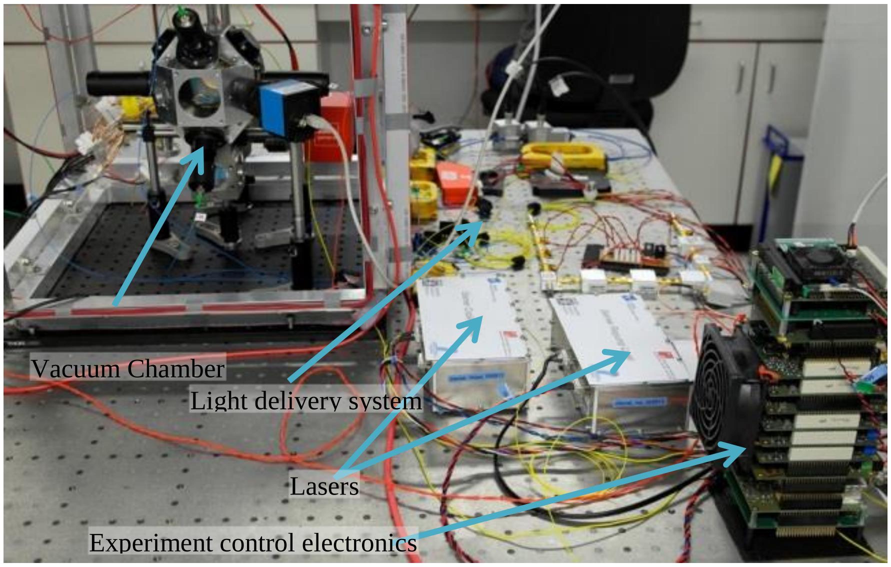

Fig. 3: Current status of the iSense setup

In the future, we hope that our developments will contribute to the application of ultracold atom technology to fields as diverse as geodesy, mineral prospection, satellite communications, portable atomic clocks, secure quantum communications, and fundamental research.

7. Acknowledgements

The project iSense acknowledges the financial support of the Future and Emerging Technologies (FET) programme within the Seventh Framework Programme for Research of the European Commission, under FET-Open grant number: 250072.

8. References

[1] Maclean, J.O., Greenaway, M.T., Campion, R.P., Pyragius, T., Kent, A.P., Fromhold, M. and Mellor, C.J., Proc. SPIE Photonics West, "III-V semiconductor waveguides for photonic functionality at 780 nm", Paper 8988-4 SPIE Photonics West, February, 2014